ELEMENTARY ELECTRO-TECHNICAL SERIES

ALTERNATING ELECTRIC CURRENTS

BY

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AND

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FOURTH EDITION, ENLARGED

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PREFACE

In preparing this little volume on *Alternating Electric Currents*, as one of a series entitled the *Elementary Electro-Technical Series*, the authors believe that they are meeting a demand, that exists on the part of the general public, for reliable information respecting such matters in electrical knowledge as can be readily understood by those not specially trained in electro-technics.

The subject of alternating-electric currents is, to-day, perhaps, the most prominent in the electrical engineering field. Although when profoundly treated, the subject is so extremely technical as not only to necessitate the use of advanced mathematics but also to require, on the part of the student, considerable knowledge of electricity, yet the authors feel

confident that a considerable portion of the subject can readily be understood by the general public. They therefore offer this volume, with the belief that since the commercial applications of alternating currents are rapidly becoming so important, it is no longer a question of willingness, but of necessity, on the part of the general public, to become familiar with this branch of electro-technics.

PREFACE TO THIRD EDITION.

Since this volume was written, extraordinarily rapid developments have occurred in the industrial transmission and application of alternating currents. It is estimated that multiphase motors have been built in the United States to the aggregate amount of 350,000 horse-power. By the addition of seven new Chapters, however, the Authors believe that the book has been brought up to date.

PREFACE TO THE FOURTH EDITION

The advance which has been made in the applications of electricity since the last edition of this book appeared have nowhere been more rapid and extensive than in the direction of alternating electric currents. With but two or three exceptions, all of the electric power-transmission systems of the world, at pressures of five kilovolts and upwards, employ alternating currents. The tendency at the present time is towards larger generating units and higher voltages.

Alternating-current generators are not only extending their own province of high-tension power transmission, but they are also extending into the province of series arc-lighting through constant-current transformers. This province formerly pertained

almost entirely to direct-current generators of variable e. m. f. and constant current.

It is believed that the additions which have been made to the book in this edition will bring the treatment of the subject to date.

JUNE, 1906.

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ALTERNATING ELECTRIC CURRENTS.

CHAPTER I.

INTRODUCTORY.

In a river, far enough above its mouth to lie beyond the reach of tidal influences, the water constantly flows in one direction; namely, down stream, or from the source toward the mouth. Farther down the river, within the tidal limits, the direction of flow alternates, or is reversed four times in about twenty-four hours: the water flowing alternately up stream

for about six hours, and down stream for about six hours.

In continuous electric currents, the electric flow is unidirectional; *i.e.*, takes place continuously in one direction through the conducting channel, like a river above the tideway. In alternating-electric currents the direction of flow in the conducting circuit, or electric channel, is alternately reversed, like a river within the limits of tidal influence.

In a river, the current, or flow of water, changes direction but four times in every 24 hours; that is, during this time there are four alternations or changes of direction. In an alternating-electric circuit, the alternating-electric current, or flow of electricity, changes direction, or is reversed, many times per second. The number of

alternations per second is commonly called the *frequency of alternation.* In practice, the frequency of alternation is from 50 to 270; or, in other words, in practical alternating-current circuits, the electric current makes from 50 to 270 alternations per second, according to the system of machinery employed. But the frequencies of alternating currents may, under certain circumstances, greatly exceed 270 alternations per second.

In the case of telephonic circuits, over which articulate speech is transmitted, alternating-electric currents are employed, the frequency of which may be 1000 or more alternations per second. In the experiments of Tesla, in which special effects called *Tesla effects* are produced, extraordinarily high frequencies are employed, reaching sometimes millions of alternations in each second of time.

Recent investigations have shown that light is, in all probability, an effect produced in space by alternating-electric currents of frequencies reaching as high as 800 trillions per second.

In the case of a tidal stream, the time required for the flow of water to return to the condition it had at any moment, may be called the period of the stream. Thus, suppose a river at high water is just beginning to ebb; then a period will include the time required to again reach high water, and will embrace the time of one full ebb and one full flood; in this case, about 12 hours. During one period the flow of water in the river will have completed one cycle, and will have undergone two alternations, or reversals of direction. Every complete cycle, therefore, consists of two alternations. In the case of the

river, the duration of ebb and flood are unequal. In the case of all practical alternating currents, the duration of each reversal or alternation is the same.

The *period* of an alternating-electric current is the time required to complete two alternations, or, in other words, to effect one complete *cycle*. The number of cycles per second is called the *frequency*. The time occupied in each reversal is sometimes called a *semi-period*. Consequently, an electric current, making 100 reversals or alternations per second, would have a frequency of 100 alternations, or 50 complete cycles, per second.

In the case of most tidal streams, the water rises or falls at a comparatively uniform rate; that is, if the range of the tide is six feet, and the difference of level pro-

duced during ebb or flood is rigorously one foot per hour, then the level of the water in the river, at any time, might be graphically represented as in Fig. 1, where we assume that at noon, each day, high water occurs three feet above the mean level; at 3 P. M. the mean sea level is reached; at 6 P. M., low water; at 9 P. M.,

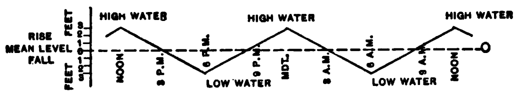


FIG. 1.—TIDAL FLOW OF RIVER.

mean level, and at midnight, high water, completing the cycle in a period of 12 hours. In this ideal case, the water is flowing from noon to 6 P. M. and from midnight to 6 A. M. out of the river, at a steady rate, of say 500,000 gallons per hour, and is flowing, at the same rate, from 6 P. M. to midnight, and from 6 A. M. to

noon, steadily back into the river. If, therefore, it be required to represent the rate-of-flow of the river, that is, the quantity of water passing per hour, or per second, it will be necessary to employ a new diagram, such as that shown in Fig. 2. Here distances above the line 0 0, corre-

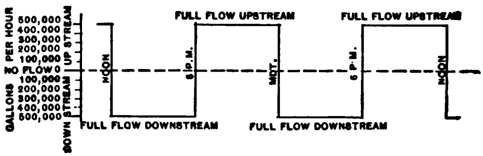


FIG. 2.—CURVE OF TIDAL FLOW.

spond to flood tide, or flow up stream, and distances below the line, correspond similarly to ebb tide, or flow down stream. Thus, between noon and 6 P. M., 500,000 gallons per hour, or nearly 140 gallons per second, flow steadily down stream toward the mouth, while from 6 P.M. to 12 midnight, there is the same flow up stream.

If the above diagrams represented the actual condition of affairs, high water and low water could only exist for an infinitesimally small interval of time, whereas, we know that slack water has an appreciable duration, and that the rate of rising or falling is not uniform, but is greatest about

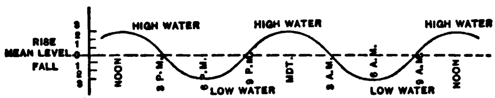


FIG. 3.—TIDAL LEVEL OF RIVER.

mean tide. This is represented for the ideal case of a 12-hour period and a uniform tide, in Fig. 3, and the flow diagram in Fig. 4, corresponding to Fig. 3, shows that the rate-of-flow, instead of changing direction abruptly, does so gradually, so that instead of the rectangular wave of Fig. 2, we have a smooth wave.

Figs. 2 and 4 may also be taken to represent alternating-electric current flow as well as alternating tidal flow, except that a period would then correspond to but a fraction of a second, instead of approximately 12 hours, and the rate-of-flow

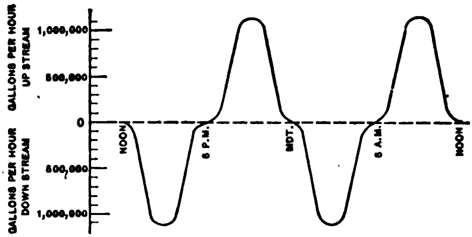


FIG. 4.—CURVE OF TIDAL FLOW.

would be measured or marked off, not in *gallons*-per-hour, but in units of electrical flow called *coulombs*-per-second.

Fig. 5 is a reproduction of Fig. 2, except that the period is 1-100th of a second, corresponding to an electrical frequency of

100 cycles, or 200 alternations per second; while the flow is alternately, say 50 coulombs of electricity per second in one direction, and then 50 coulombs-per-second in the opposite direction.

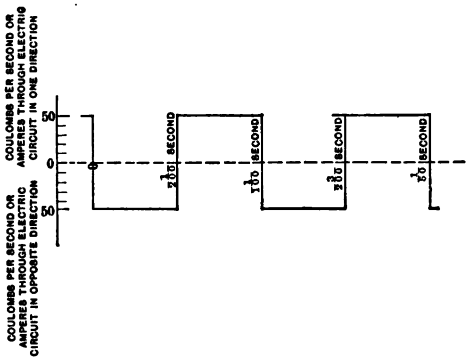


FIG. 5.—CURVE OF ALTERNATING-CURRENT FLOW.

A coulomb-per-second, considered as a rate of flow, is called an *ampere*. Instead, therefore, of using the phrase coulomb-per-second, we may use the word ampere.

The current strength, or flow, represented by Fig. 5, is alternately 50 amperes in one direction and 50 amperes in the opposite direction throughout all parts of the conducting circuit.

In an alternating-current circuit, that is, in a complete conducting path through which alternating-electric currents may flow, the current strength, at any instant, as expressed in amperes, is the same at all parts of the circuit, so that if the current strength be 50 amperes in one direction, it will, as a rule, at that moment, be 50 amperes in that direction throughout the circuit, and, when the reversal takes place, it will practically do so coincidently throughout the circuit, and the current strength becomes, as is seen in Fig. 5, 50 amperes in the opposite direction in all parts of the circuit.

Fig. 6 is practically a reproduction of Fig. 4, and represents an alternating current with a frequency of 50 cycles, or 100

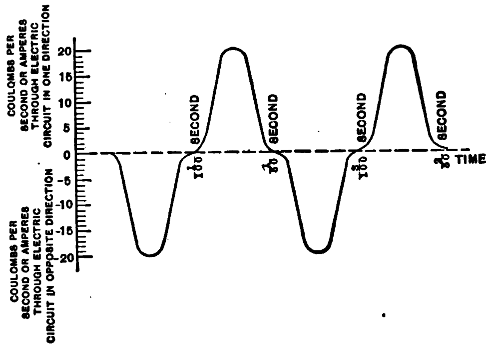


FIG. 6.—CURVE OF ALTERNATING-CURRENT FLOW.

alternations per second, and a maximum strength of 20 amperes in each alternation. The condition of things represented in Fig. 6, is a much closer approximation to the actual state of most commercial alternating-current circuits than that represented in Fig. 4, since, in fact, the electric cur-

rent can never change instantaneously from a full positive to a full negative strength, or vice-versa, but usually follows some smooth curve.

For convenience, we have compared the flow of water through a river channel with the flow of electricity through a conducting channel or circuit. We should, however, carefully avoid falling into the error of carrying this analogy too far, since electricity is not a fluid, although many of the laws of its passage and flow bear close resemblance to the laws of liquid flow.

Although, at the present time, the exact nature of electricity is far from being known, yet electricity is generally believed to be an effect produced by an active condition in an all-pervading medium called the *ether*. The ether is believed to fill in-

terstellar space and to permeate all bodies, even copper wires, and other equally dense forms of matter. Just what may be the nature of that particular ether activity which constitutes electricity, is not known. It may or may not resemble the particular form of activity in the atmosphere called whirlwind.

The difficulty of obtaining a clear conception of the true nature of electricity arises from our inability to recognize even the existence of the ether by our senses, and our still greater inability to recognize the conditions of its activity. In the case of the atmosphere, we can readily appreciate the phenomena produced by the wind, since the effects are produced on a scale commensurate with the capabilities of our senses. But, were we situated on a distant planet, and had no experience what-

ever of an atmosphere, even though we could perceive, through sufficiently powerful glasses, the effects of storms on the earth, we would, probably, have as great difficulty in understanding the nature of phenomena produced by wind power, as we now have in understanding the nature of electrical phenomena, as possible effects of ether disturbance.

The researches of the eighteenth century gave rise to the belief that electricity was a subtle fluid to which the name of electric fluid was given. The researches of the nineteenth century have promoted the belief that this fluid is no other than the all-pervading ether which serves to convey over apparently empty spaces heat, light, gravitational force, and magnetism. Certain characters of disturbance in this medium produce phenomena which we recognize as electrical, while other dis-

turbances of a distinct but interconnected character with the preceding, give rise to phenomena which we recognize as magnetic.

CHAPTER II.

ALTERNATING ELECTROMOTIVE FORCES AND CURRENTS.

In all commercial applications of electricity the following combinations of parts are needed; namely,

(1) A device called a *source*, where the electric current originates.

(2) Devices called *translating* or *receptive devices*.

(3) *Conducting paths* connecting the translating devices with the electric source.

In all cases, after an electric current has left its source and produced some peculiar effect in a receptive device, placed in its path or circuit, means must be provided

whereby the current may flow back again to the source. In other words, the electricity invariably leaves the source, passes through various conducting paths, produces effects in the translating devices, and flows back to the source from which it came. For this reason, the conducting path is usually called a *circuit*, although of course it is not necessary that the path through which the electricity flows should be a circular path.

Electric sources do not primarily produce electricity, but a particular variety of force called *electromotive force*, (generally abbreviated E. M. F.). This force, in its turn, tends to produce electric current. In point of fact, an electric source, although it will always produce electromotive force in a conducting circuit connected to it, yet will not produce an elec-

tric current in such circuit, unless the circuit be *closed* or *completed.*

Electromotive forces are either *continuous* or *alternating.* A continuous electromotive force is *unidirectional; i. e.*, has continuously the same direction, and produces, when it acts upon a closed circuit, what is called a *continuous* electric current. An alternating electromotive force is one which alternates in direction, and, when applied to an electric circuit, produces an *alternating* electric current; that is, an electric current, the direction of which periodically changes with the change in the direction of the E. M. F.

A voltaic cell is an example of an electric source which produces a continuous electromotive force. A common and convenient form of voltaic cell, much employed on telegraph lines, is called the

Daniell Gravity Cell. Such a cell is shown in Fig. 7. It consists of a plate of copper *C*, and a plate of zinc *Zn*, immersed respectively in aqueous solutions of copper

FIG. 7.—GRAVITY CELL.

sulphate and zinc sulphate. A solution of zinc sulphate will float on a solution of copper sulphate, being lighter than it, and since this fact is utilized to keep the liquids separated, the form of cell in which the solutions are thus separated, is called the gravity cell.

The current produced is conventionally assumed to leave the cell at its *positive* or copper pole, and to return to it, after having passed through the conducting circuit, and its receptive device, at its *negative* or zinc pole. When the terminals of the cell

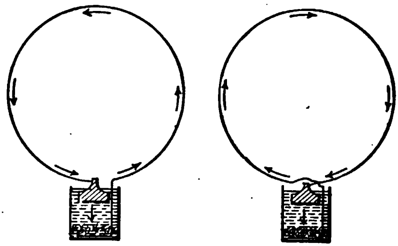


FIG. 8.—ILLUSTRATING REVERSAL IN DIRECTION OF CURRENT THROUGH AN ELECTRIC CIRCUIT ON THE REVERSAL OF ITS ELECTROMOTIVE FORCE.

are connected to a circuit, a current will flow through the external circuit from the copper pole to the zinc pole, as shown in Fig. 8. But if the terminals of the cell be reversed, the direction of the flow through the conductor will be reversed,

and, if these reversals are made five times per second, then there will be five alternations of electromotive force and current in the circuit per second. The alternating currents employed in practice, are not, however, obtained in this way, but from special machines called *alternators*.

In its action on an electric circuit, a continuous electromotive force resembles the action of a *watermotive force*, or pressure in a reservoir, which forces a steady stream of water through an outflow pipe. An alternating electromotive force resembles in its action the action of an *alternating watermotive force*, or pump, alternately pumping water into and out of a reservoir through a pipe. Water engines, operated by water pressure alternately exerted on opposite sides of a piston, after the general manner of the action of a steam

engine, afford an instance of such an alternating watermotive force.

When a continuous electromotive force is applied to a conducting circuit, such, for example, as a mile of insulated copper wire, the current which passes through the circuit will be twice as great as it would be, if the same E. M. F. were applied to a circuit of the same length of such wire, but of only half the weight or area of cross-section; for, the thicker wire conducts electricity twice as well as the thinner wire; or, in other words, offers but one-half the resistance.

Electrical resistance is usually expressed in units called *ohms*. The ohm is the resistance offered by a given length of conductor of definite cross-section. When the resistance of any circuit is

known in ohms, the current, produced by applying to this circuit a known E. M. F., can be calculated in amperes, by a rule called *Ohm's law*, from the name of its discoverer, Dr. Ohm, of Berlin.

Ohm's law is usually expressed as follows:

The current in any conducting circuit, expressed in amperes, is equal to the total electromotive force in the circuit, expressed in volts, divided by the resistance of the circuit, expressed in ohms.

In other words, the amperes in any circuit are equal to the volts divided by the ohms. Thus, the electromotive force usually supplied to incandescent electric lamps is about 110 volts, and since the resistance of the carbon filament in a sixteen-candle power lamp, when lighted, is, say 220 ohms, the current strength,

which will pass through such a lamp, is 110 volts ÷ 220 ohms = 1·2 ampere.

If the electric resistance of any insulated wire be measured in ohms, the value will be found to be the same, whether the wire be straight or bent; *i.e.*, whether the wire be stretched in a straight line, or be wrapped in a close coil; for, when a continuous current is once established in a wire or conductor, bends or turns in the direction of the conductor do not offer any additional resistance to the flow of the current. When, however, an alternating electromotive force is applied to a wire, the strength of the current established in the circuit is considerably influenced by the disposition of the wire, that is, whether it forms a single loop, or whether it forms a coil of many turns. In the latter case, the current which

flows is much smaller than that obtained by dividing the E. M. F. in volts, by the resistance of the coil in ohms. In other words, a different law appears to govern the current strength in an alternating-current circuit than that which governs it in a continuous-current circuit. A circuit containing coils of wire, acts toward an alternating E. M. F. as if it possessed a higher resistance than when traversed by a steady current. In other words, the passage of an alternating current through a coil of wire is opposed by an influence which tends to choke or diminish the current. This influence is called the *reactance* of the coil. The nature of reactance will be understood from a consideration of the following principles: When an electric current is sent through a conductor, the conductor thereby acquires all the properties of a magnet, as was first

shown by Oersted, in 1819. Could we see the actual state of things which exists in the neighborhood of an active conductor, it is believed that we would be able to see around the conductor, a streaming motion in concentric circular paths, of the highly tenuous, all-pervading medium, called the ether.

The ether streaming motion is called *magnetism*. It is most energetic in the immediate neighborhood of the conductor, gradually becoming weaker at greater distances from it. Moreover, the direction of the streaming depends upon the direction of the current in the conductor. For example, if, as in Fig. 9, the current passes downward through the plane of the paper, that is, from the observer, the direction of the streamings will be the same as the direction of the hands of a watch.

These ether streamings occur in the space around every magnet, as well as in the space around an active conductor, and constitute what is called a *magnetic field.*

If the conductor be given the form of a

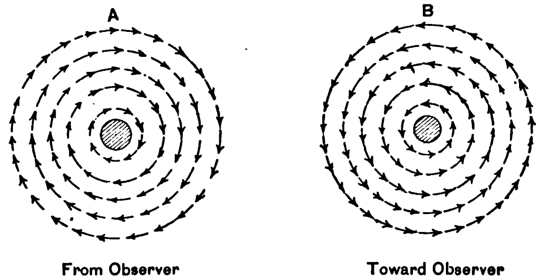


FIG. 9.—DIAGRAMS OF FLUX PATHS ROUND A WIRE CARRYING A CURRENT FROM AND TOWARD OBSERVER.

loop and the ends of the loop be connected with an electric source, so that an electric current flows through the circuit so formed, then the ether streamings, or the magnetic flux surrounding the wire, will be so directed that all the flux will enter

the loop at one side and leave it at the opposite side. The only effect produced by changing the direction of the current, will be to change the direction in which the flux passes through, or threads the loop. If, for example, with one direction of current flowing through the conducting loop, the magnetic flux enters the loop from above and passes out below, then reversing by the direction of the electric current, the flux would enter the loop from below and pass out from above.

The effect of impressing any E. M. F. on a conducting loop is, therefore, to cause magnetic flux to thread or pass through the loop. Conversely, the effect of causing magnetic flux to pass through a loop is to produce an E. M. F. in the loop. This E. M. F. continues only while the flux passing through the loop is changing in

amount; or, in other words, while it is increasing or decreasing. An E. M. F. set up in this manner in a conducting loop is called an *induced* E. M. F. The direction of the induced E. M. F. is opposite to the direction of the E. M. F. which was required to produce the flux that caused it. In order to distinguish the E. M. F. producing the flux, from the E. M. F. produced by the flux, the former is called the *impressed* E. M. F. In other words, the passage of magnetic flux through a conducting loop, consequent upon the application of an E. M. F. to such loop, will tend to set up in the loop an E. M. F. oppositely directed to that of the impressed E. M. F. The induced E. M. F. is, consequently, called a *counter electromotive force;* and, since it is produced by induction, it is sometimes called the *counter electromotive force of self-induction.*

The intensity of the counter E. M. F. so set up, depends upon the rate of change in the amount of flux passing through the loop at any moment, and not on the total amount of flux. Consequently, when the direction of current is reversed, as in an alternating-current circuit, the direction of the flux is reversed, and a rapid change occurs in the rate at which the flux is passing through the loop.

The effect, therefore, of applying an alternating E. M. F. to a coil of wire is to produce, by induction, a resistance to current flow greater than the resistance to steady currents. This total apparent resistance, which is generally called *impedance*, arises from the fact that the rapid filling and emptying of the coils with magnetic flux, set up an E. M. F. counter or opposed to the E. M. F. driving the flux

through the coils, and, therefore, impedes the flow of current through the coils. The effect of the impedance is to prevent the immediate application of Ohm's law to an alternating-current circuit.

The resistance of 100 feet of insulated copper wire of the size represented in Fig. 10, and which is known commercially as

FIG. 10.—NO. 13, A. W. G. WIRE, FULL SIZE.

No. 13, American Wire Gauge, contracted *A. W. G.* is approximately 1-5th of an ohm. If a continuous E. M. F. of one volt be maintained between the ends of this wire, the current strength through the wire, whether straight or wound into a coil, would, by Ohm's law, be five amperes (1 volt ÷ 1-5th ohm = 5 amperes). But if an alternating E. M. F. of one volt, reversing

250 times a second, and, therefore, having a frequency of 250 reversals, or 125 cycles per second, be connected to the ends of the wire, the current strength through the wire, if the wire be wound into a coil of many turns, will be considerably reduced, say to 2 amperes, and the impedance, or *apparent* resistance of the wire, will be 1-2 ohm, instead of 1-5th ohm.

The impedance increases both with the frequency and with the number of turns in the coil. But, as we have already seen, a counter E. M. F. is produced in a coil by a change of flux passing through the coil. The effect of introducing iron into the path of the magnetic flux, is to increase the amount of flux which passes, owing to the fact that iron conducts magnetic flux much better than air. If, then, a coil of wire be wound on a suitable core

of iron, the flux passing through the coil, at each reversal of current, will be greatly increased, and, consequently, the reactance of the coil will be increased, or the coil will possess a greater impedance and a more marked choking effect, when the core is present, than when it is absent.

It might be supposed that alternating-electric currents possess a marked disadvantage over continuous currents from the fact that the introduction of coils of wire into their circuit necessarily tends to impede or choke the current flow; for, as is well known, nearly all electric apparatus contain coils of wire, as, for example, electromagnets. But this very fact, so far from being an unmitigated detriment, is often employed to great advantage, where the amount of current which can flow through a circuit is automatically choked

or throttled by the impedance of coils of insulated wire. In fact the capability of introducing reactance, practically without resistance, into an alternating current circuit, is one of the principal advantages of alternating currents.

It is true that an electric current, whether continuous or alternating, can be readily diminished in strength by the introduction into the circuit of mere resistance, called *ohmic* resistance, because its resistance depends only on the nature of the wire, its length and area of cross-section, and is independant of the disposition of the wire, or its coiling. But, in the case of an alternating current, the counter E. M. F. prevents a portion of the electromotive force from acting and, therefore, decreases the amount of electrical work done, or energy usefully ex-

pended, while with the continuous current, although the current is reduced, yet the entire E. M. F. is acting and, consequently, there is a greater expenditure of power.

An application of the methods of varying, in certain cases, the strength of current flowing through any circuit, is seen in the solution of a problem, which is often met in practice; namely, to turn down or decrease the brightness of an electric lamp. If this be done, as has frequently been attempted, by introducing into the circuit of the lamp, a mere ohmic resistance; namely, a conductor with but a few turns, then, although the strength of current passing through the lamp is decreased, and power saved in this respect, yet the same current is now passing through the resistance and producing use-

less heat in it. On the contrary, when a reactance, *i. e.*, a coil of many turns, is employed with an alternating current, not only is the current passing through the lamp decreased, but practically no energy is lost in the reactance.

Fig.11 represents a form of device for turning down lights, called a *theatre dimmer*. Here a portion of the circuit containing the lamps is wrapped in the form of a coil *C*, around a laminated ring of soft iron *K*; that is, a ring consisting of plates of soft sheet iron, laid side by side. On the opposite side of the soft iron ring *K*, a copper shield *H*, is placed, capable of being slid over the core *K*, to the right or the left about the axis *D*, by the motion of the hand wheel. With the relative positions occupied by the shield *H*, and the coil *C*, shown in the figure, the

effect of the coil is to throttle, or choke, the current, by its reactance, and thus diminish the intensity of the light given by the lamps. If it be desired to increase the amount of light, that is, to turn the

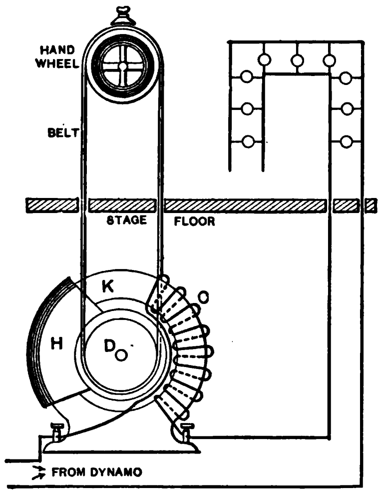


FIG. 11.—THEATRE DIMMER, REACTIVE COIL.

lights up, the metal shield *H*, is moved by the hand wheel toward the reactive

coil C, thereby diminishing the reactance of the coil, and thus permitting more cur-

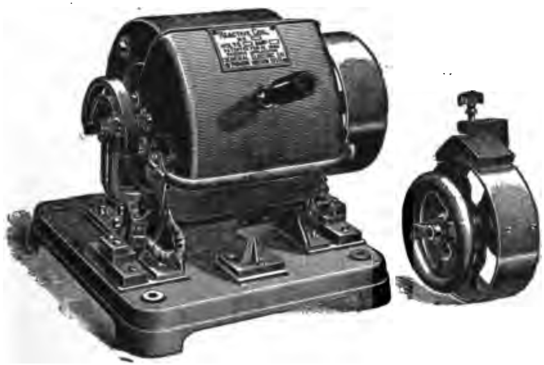


FIG. 12.—THEATRE DIMMER.

rent to flow through the circuit. A motion, therefore, of the metal shield H, toward C, increases the intensity of the light, while a motion from C, diminishes the intensity. A perspective view of the apparatus is shown in Fig. 12. Fig. 13 shows other forms of theatre dimmer, which operate by the choking effect of react-

ive coils furnished with a movable core consisting of a bundle of soft iron wires.

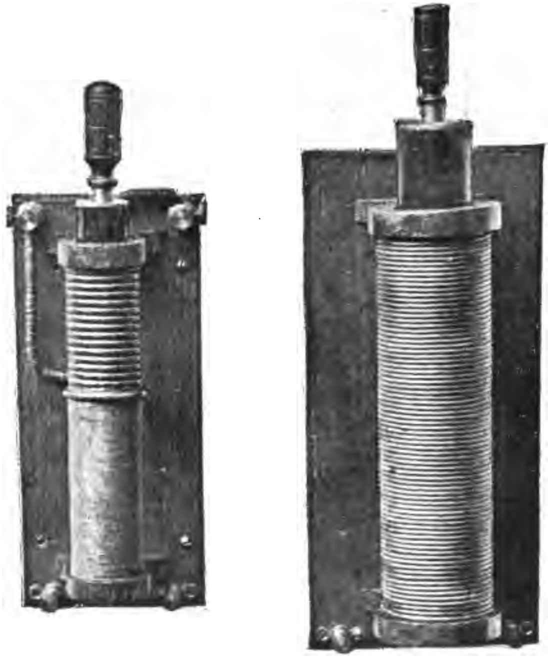


FIG. 13—ALTERNATING CURRENT THEATRE DIMMERS.

Both continuous and alternating currents are capable, when passed through

coils of insulated wire provided with iron cores, of producing electromagnets as shown in Fig. 14. Continuous-electric currents are generally employed for this purpose, since the magnetizing coils do not then act to throttle the current. When alternating-electric currents are passed through the coils of an electromag-

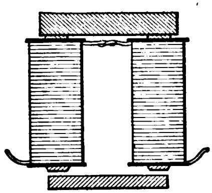


FIG. 14.—FORM OF ELECTROMAGNET.

net, although such a magnet does not possess as powerful attraction for its armature, as when excited by continuous currents, yet it often possesses the advantage of exerting a more nearly uniform pull over a greater distance. Of course, in alternating-current electromagnets, the

magnetism is constantly reversing in direction, with each reversal of the current, each pole becoming alternately of north and south polarity.

In electroplating, deposits of gold, silver and other metals are thrown down by the action of an electric current on the conducting surfaces of articles placed in suitable vats. The surfaces which are to receive these deposits, if not already conducting, are made so by various processes, and immersed in solutions of the metals with which they are to be coated. The current employed for this purpose is invariably a continuous current. It is a well-known fact, that an article, which has been placed in a plating bath and has received a coating of deposited metal by the electric current passing through the bath in a certain direction, will have all this

metallic coating gradually dissolved if the current be sent through the bath in the opposite direction; for, in all cases of electro-plating, the metal is only deposited on one of the conducting surfaces connected with the poles; *i.e.*, on the negative, and is dissolved from a plate of metal connected with the opposite or positive pole. Since, in an alternating-current circuit, both the article to be plated and the plating metal become alternately positive and negative, it might be supposed that it would be impossible to produce any permanent plating whatever by such a current, and, although this is true to the extent of preventing plating from being carried out practically by such methods, nevertheless, permanent electro-plating effects can be produced by alternating currents, when certain relations exist between the size of the article to be

plated and the strength of the current passing.

So far as the heating effects of the electric current are concerned, alternating currents produce the same amount of heat that continuous currents do. For example, if an incandescent lamp be connected to a continuous-current circuit of 110 volts pressure, and, subsequently, to an alternating-current circuit of 110 volts pressure, the amount of light and heat, which the lamp will give off, will be the same in both cases.

A marked difference exists between the physiological effects of an alternating and a continuous current. When a continuous current is sent through the human body, chemical and physiological effects are produced, entirely distinct from those which

attend the passage of an alternating current under similar circumstances. When passing through the vital organs of the body, any electric current, whether continuous or alternating, may, if sufficiently powerful, cause death. Alternating currents, however, at commercial frequencies and pressures, are much more apt to produce fatal effects on the human body than continuous currents. In New York State, alternating electric currents are used for the execution of criminals, and, when properly employed, produce absolute, instantaneous, and painless death.

The experiments of Tesla and others have shown that at frequencies and pressures far higher than those employed for ordinary commercial purposes, the physiological effects of alternating currents become less severe, and that at extraordina-

rily high frequencies, enormous pressures may be handled with impunity.

It should be remembered, however, that the physiological effects produced by a current depend largely on the resistance offered to its passage through the body by the skin. For example, when an alternating current is sent through the human body, by immersing the hands in saline solutions connected with an alternating-current circuit, a pressure even as low as five volts will usually produce very painful sensations. Care, therefore, should always be taken in handling the wires from any high-pressure electric source particularly if that source be one supplying alternating currents.

In an alternating-current circuit, both the strength and the direction of the E. M. F. and current are periodically varying,

being at certain times at greatest strength and at others entirely absent. It is evident that it would not be correct to estimate the value of an E. M. F. or a current at either its greatest or its least value; nor is it usual to take the average value. Instead of this a certain value, both of the E.M.F. and the current, called respectively the *effective E. M. F.* and the *effective current strength*, are taken as estimated from their equivalent heating effects. Thus, an alternating-current pressure of 100 volts is one which, as already mentioned, will produce in an incandescent lamp the same heating and, therefore, the same degree of illumination as 100 volts of continuous-current pressure. In the same way an alternating-electric current, whose values at different successive instants in any cycle would be considerably above or below one ampere, would be regarded as having an

effective current strength of one ampere, if it produced the same heating effect in a coil of wire as a continuous electric current of one ampere.

This method of estimating the values of alternating E. M.F.'s and currents is universally employed, and entirely dispenses with the necessity for a determination of the shapes of the alternating-current waves, just as any method of measuring tides, which depended upon a measurement of the total quantity of water moved up stream during each tide, would dispense with the necessity for determining the exact shape of the tidal wave.

CHAPTER III.

UNIPHASE ALTERNATORS.

DURING the last few decades there has been witnessed a marvelous development in the commercial applications of electricity. Perhaps the most striking feature in this development is to be found in the strength of the electrical currents employed to day, as compared with the strength of those which were commercially possible only a few years ago. Electricity has commercially entered fields, which, but a comparatively short time ago, would have been closed to it by reason of the expense attending its production.

This development has not been rendered possible so much by improvements

in the apparatus operated by electricity, as it has been in the improved methods for producing electricity more cheaply. For example, to take the field of electric lighting, in which the most marked developments were first manifested; although the arc lights of to-day are, in their way, marvels of mechanical and electrical ingenuity, yet, in point of fact, they do not differ radically, in their general construction, from those produced fifty years ago. Why then did not these early arc lamps enter into more general use? Surely not on account of any lack of appreciation on the part of the general public, of the advantages possessed by the voltaic arc as an artificial illuminant, but because, in those early days, the only practical means for producing electrical currents was an expensive and inconvenient source of electric supply; namely, the primary, or

voltaic battery. That which rendered electric lighting, as well as most of the many other commercial developments of electricity which followed in its wake, commercially possible was the production of a means for cheaply producing electricity, on a large scale; viz the invention of the generator known as the dynamo-electric machine.

It is a well-recognized principle, in the physical world, that in order to perform work of any kind, whether mechanical, chemical or electrical, energy must be expended. Consequently, the production of a definite amount of electrical energy requires the expenditure of a definite amount of work.

A machine is a device for transforming one kind of work into another. Thus a steam engine and boiler form a machine

for transforming, into mechanical work, the work of heat, liberated by the burning of coal. Despite the fact that the steam engine has been repeatedly improved, since the early days of Watt, in 1765, yet in the best forms of triple-expansion engines, as produced to-day, the work delivered by the engine amounts to but about sixteen per cent. of the work delivered by the coal; so that, although the steam engine can transform the work of heat into mechanical motion, it throws away, during the process of transformation, five parts out of every six. Contrasting with this the modern dynamo machine, the latter will be found a far more efficient agent for the transformation of energy; for, even in small sizes, of say one H.P., it is capable of delivering, as electrical work, 75 per cent. or about three parts out of every four, of the mechanical work ex-

pended in driving it, while in large sizes, of, say thousands of H.P. it is capable of delivering as electrical energy 98 per cent. of the mechanical energy it receives.

Although in practice dynamo-electric machines are generally driven by steam engines, yet their economy over other electrical sources is so great as to warrant this use, despite the low efficiency of the steam engines. Since the expense of maintaining steam power decreases markedly with the size of the steam plant, and since, as we have seen, the capability of the dynamo increases with its size, it is generally found more expedient, in practice, to generate electrical currents in large quantities at a few points called *central stations*, distributing the electrical power to consumers by means of suitable distribution circuits, than it is to have

as many individual plants as there are consumers of the electric current. This is especially the case where dynamos are driven by cheap water power.

A visit to any central station, where electricity is being generated on a commercial scale, will, on even a casual observation, enable one to readily divide the machinery into two distinct classes; namely, the *driving machinery* and the *driven machinery*. The driving machinery will consist either of steam engines or of water wheels. The driven machinery will consist of various forms of dynamos. The driving and driven machinery are connected together, either by means of *belting* or *ropes*, or are rigidly coupled together on the same shaft.

At first sight it may seem that different types of dynamo machines differ radically

in their detailed construction. A closer inspection, however, will show that such differences are apparent rather than real; for it will then be seen that all have certain parts in common; namely, the part called the *armature*, in which the electric current is generated, and the part called the *field magnet* in which the magnetic field of the machine is generated.

Attention has already been called, in the second chapter, to the fact that when loops of wire are filled and emptied with magnetic flux, *electromotive forces* are generated in the wire. The *dynamo-electric machines* that we see operating in a central station, are devices for filling and emptying, with magnetic flux, conducting loops that are placed on the armature of the machine. In order to do this, either the armature or the field is rotated. Usually

it is the armature that is rotated, since the armature is generally the lighter part.

The E. M. F. generated in such conducting loops, reverses its direction twice during each rotation of the armature in a *bipolar field; i. e.*, a field having one north and one south pole. All dynamo-electric machines are capable of ready division into two sharply marked classes; namely, those in which alternating E. M. F.'s are delivered to the consumption circuits, that is, the circuits external to the machine, producing in them alternating-electric currents, and those in which such E. M. F.'s are commuted, or given the same direction, by means of devices called *commutators*. In other words, all dynamo-electric machines can be divided into *alternating-current dynamos* or *alternators*, and *continuous-current dynamos.*

We have, therefore, a general principle by means of which we can determine whether or not a given machine, which we are examining in a central station, is an alternator, or a continuous-current dynamo, since, in the case of the alternator, the conducting loops of wire on the armature are connected directly to the external circuit, generally by means of brushes resting on simple *collector rings*, while in continuous-current dynamos, the brushes, instead of resting on collector rings, rest on a commutator, which differs from the rings in the fact that it consists of a number of separate conducting bars, insulated from one another.

The preceding principle, however, needs some modification, since the requirements of electrical engineering, sometimes, render it advisable to construct dy-

namos so as to render them capable of giving simultaneously both alternating and continuous currents. Various methods are adopted to obtain this result. For example, in some cases a portion of the conducting loops on the armature have the alternating E. M. F.'s generated in them so commuted as to produce a continuous current, while the remaining loops are connected directly to the collector rings, from which the alternating currents are carried off to the consumption circuits, by means of brushes resting on the rings. In such cases, the continuous currents are employed for various purposes, generally for the excitation of the magnetic field through which the armature revolves, which excitation must always be provided by continuous currents.

In all alternators, therefore, continuous

currents must be provided to flow through the field coils. Such continuous currents are either supplied by the machine itself, by commuting a portion of the conducting loops on the armature, or are supplied from a separate source. In other words, all alternators can be divided into two sharply marked classes; namely, those that are *self excited*, that is, supply their own field magnets with continuous currents, and, therefore, must be supplied with a commutator in addition to the collector rings; and those which are *separately excited*, or which derive the continuous currents for the excitation of their field magnet coils from some external source.

Let us now examine some of the dynamos that are commonly met with in central stations in the United States. Take, for example, the dynamo shown in Fig. 15.

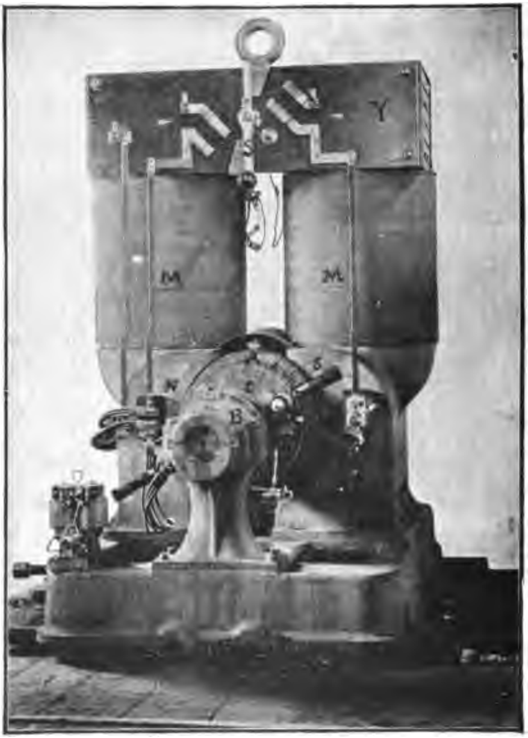


FIG. 15.—BIPOLAR CONTINUOUS-CURRENT GENERATOR.

This is a *bipolar dynamo;* that is to say, its field magnets *M*, *M*, excited by large coils of wire as shown, produce two poles, *N* and *S*, between which the armature *A*,

FIG. 16.—QUADRIPOLAR CONTINUOUS-CURRENT GENERATOR.

is revolved. An inspection of this machine will show that it must belong to the continuous-current type, since the brushes

rest on a commutator *C*, composed of numerous insulated copper bars.

Fig. 16 shows a type of *quadripolar dynamo;* or a dynamo whose field magnet coils, *A*, *B*, *C*, *D*, produce four poles between which the armature revolves. Here again this machine evidently belongs to the continuous-current type, since its brushes, in this case four sets, evidently rest on a commutator, *M*.

Fig. 17 shows a type of separately-excited alternator. Here a small continuous current dynamo D_1, provided with a commutator at *C*, supplies a continuous current through the brushes *B*, to the conductors 1 and 2, to the 12 field magnets *M*, *M*, etc., of the alternator *D*.

In any bipolar generator, whether con-

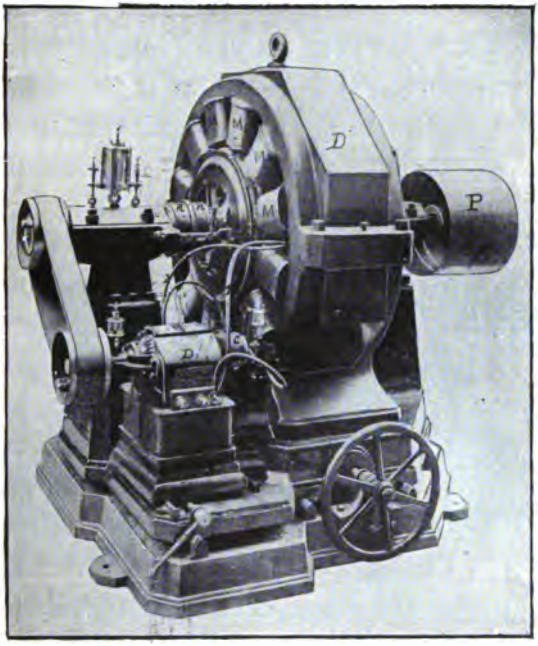


FIG. 17.—SEPARATELY-EXCITED ALTERNATOR.

tinuous or alternating, the two poles are respectively North and South. In a quadripolar machine, such as represented in

Fig. 16, the poles are alternately North and South; and, in general, in generators containing any number of poles, the polarity is alternately North and South, as are the 12 poles in Fig. 17. A moment's thought will show that a *multipolar generator* must, therefore, necessarily contain an even number of poles, since any odd number of poles would bring two poles of the same polarity in juxtaposition. In the alternator shown in this figure, the currents produced by the armature are carried to the external circuit, as alternating currents, by means of brushes resting on the collector rings *R*, *R*, which, according to the principles already explained in Chapter II, become alternately positive and negative during the rotation of the armature past each pole.

Fig. 18 shows another form of separately-

excited alternator. Here the continuous-current generator, instead of being separate from the machine, and connected with it by a belt, as in Fig. 17, is mounted on the

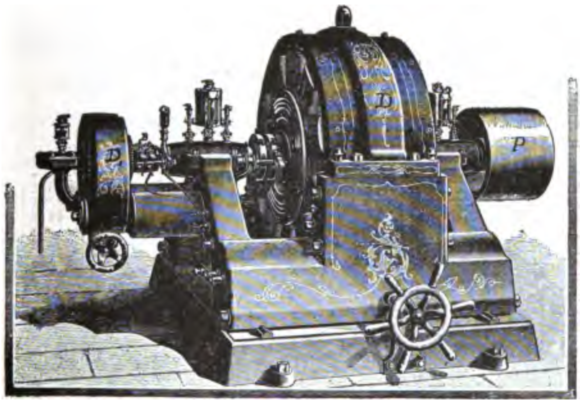


FIG. 18.—SEPARATELY-EXCITED ALTERNATOR.

same shaft as the alternator at D_1, and a continuous current, taken from the commutator and brushes B, is led to the field magnets M, M, of the alternator D. The alternating currents produced in this gen-

erator are carried to the external circuit by means of brushes resting on the collector rings *R*, *R*. The main driving pulley of the machine is shown at *P*.

Heretofore, all the generators we have examined have had but a single circuit of wire on their field magnet coils. Sometimes, however, it is necessary to provide two separate circuits in the exciting coils on the field magnets. Such machines are called *compound-wound*, or *composite machines*. The object of *double-winding* on the field magnets is to maintain automatically the same pressure at the terminals or brushes of the alternator, whether it is supplying a strong or a weak current in its circuit; or, as it is sometimes termed, to *regulate automatically* the pressure under all loads. Fig. 19 represents such a *self-regulating compound-wound alterna-*

tor. Here one of the circuits on the field magnets *M*, *M*, is separately excited by the continuous - current generator D_1. The other circuit on the field magnets is ex-

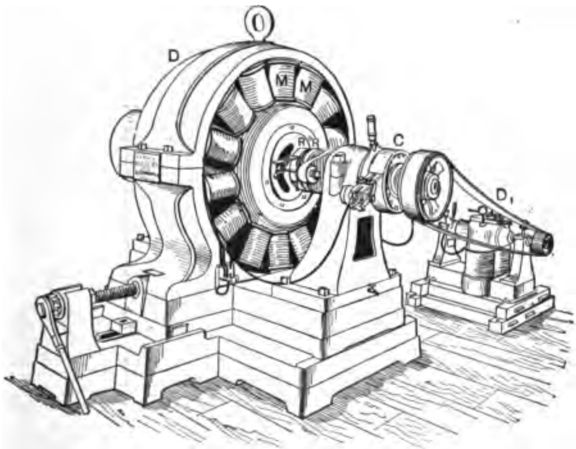


FIG. 19.— COMPOUND - WOUND, SEPARATELY - EXCITED ALTERNATOR.

cited by a portion of the alternating current supplied by the machine, and which is commuted by a commutator *C*. The

alternating current is carried to the external circuit by the rings R, R.

The electrical connections of such a compound-wound machine are shown in Fig. 20. Here the exciter D_1, sends from

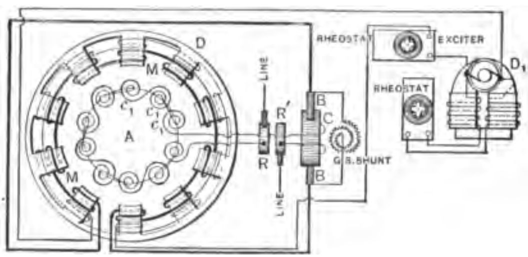


FIG. 20.—DIAGRAM OF CONNECTIONS IN A PARTICULAR COMPOUND-WOUND, SEPARATELY-EXCITED ALTERNATOR.

its brushes a continuous current through an *adjustable resistance*, or regulating device called a *rheostat*, and through a fine wire circuit to the field coils M, M, which are connected in series. The coils C_1 C_1 C_1 etc., mounted on the revolving armature A, generate alternating currents, which are

connected to the collecting rings *R*, *R*, and to the commutator *C*, as shown; namely, one end is connected directly to the collecting ring *R*, and the other end to the ring R_1, through the commutator *C*. Under these circumstances a certain portion of the current passes around the commutator through the path marked *G. S. shunt*, of German silver wire, passing on as alternating currents to the collector ring, and by means of the brushes to the external circuit or line, as alternating currents, while the remainder, or commuted portion, is fed through the brushes *B*, *B*, to the coarse wire circuit of the field magnets. The effect of this arrangement is, that as the strength of the current supplied to the external circuit increases, the portion of this current supplied to the coarse wire circuit of the field magnets increases, and the field magnets

are thereby strengthened, thus increasing the E. M. F. of the machine by increasing the magnetic flux passing through the coils on the armature.

A self-excited alternator supplies from its own armature, through a commutator, all the current required for the excitation of its field magnets. All alternators may, therefore, be divided into three general classes; namely,

(1) *Separately-excited machines*, in which the currents required for the excitation of the field magnets are obtained from a continuous-current dynamo. Such alternators employ no commutators but only a pair of collector rings.

(2) *Self-excited machines*, which supply all the current required for the excitation of their field magnets, after such current has been rendered continuous by the ac-

tion of a commutator. Such machines, therefore, employ a commutator in addition to collector rings.

(3) *Compound-wound alternators*, which consist practically of a combination of the two preceding types. In other words, the principal excitation of the field magnets is obtained from a separate dynamo, while the additional excitation, needed to maintain a constant pressure at the collector rings under all conditions of load, is obtained from their own armature current through the action of a commutator.

Fig. 21 represents a self-excited alternator with a commutator at *C*, and collector rings at *R*, *R*, for the delivery of alternating currents to the circuit.

In order to familiarize the reader with the varieties of alternators in common use in the United States, two additional ex-

amples of alternating-current machines are given in Figs. 22 and 23. An examina-

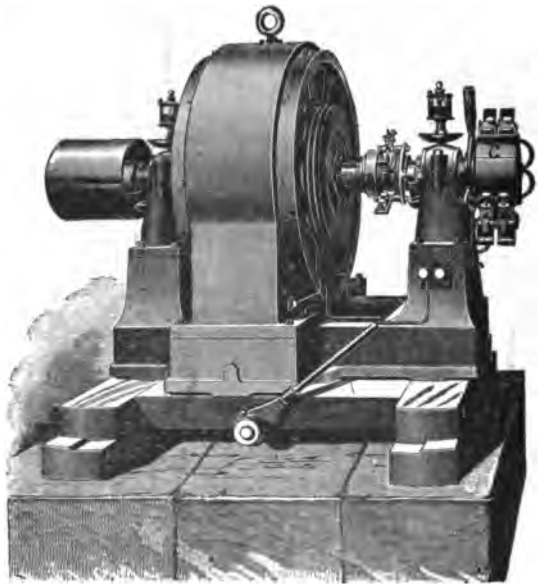


FIG. 21.—SELF-EXCITING ALTERNATOR.

tion of these figures will show that the machines represented belong to the same general type as those already described, the

differences being either in mechanical construction or in the relative arrangement of the parts. For example, Fig. 22

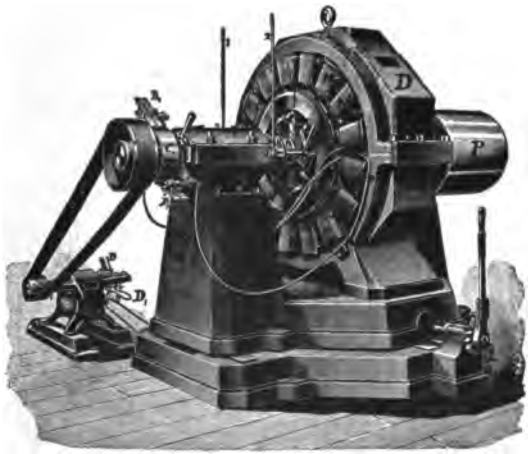


FIG. 22.—2000-LIGHT ALTERNATOR.

shows a separately-excited alternator of 16 poles with collector rings at R, R, supplying alternating currents, through the leads 1 and 2, to the external circuit. The

separate exciter D_1, supplies commuted or continuous currents to one winding of the field magnets, *M*, *M*, and part of the armature current from the alternator *D*, is supplied through the commutator *C*, to the other winding of the field coils. This machine is, therefore, a *compound-wound, separately-excited alternator*, and agrees in all essential electrical features with the machine shown in Fig. 9.

Fig. 23 shows a form of alternator in which only a pair of collector rings is employed. Here the separate exciter, necessary for supplying continuous currents to the field magnets, is not shown, and, as there is no commutator on the machine, it is clearly not compound-wound. This alternator corresponds electrically to the type of machine shown in Fig. 7.

Beside the forms of alternators above

described, there are many others. All, however, possess the same fundamental features although these features may dif-

FIG. 23.—1000-LIGHT ALTERNATOR.

fer markedly in their construction details. For example, in some alternators the armature is fixed and the field rotates. In others, both armature and field are fixed,

but a rotating frame is so placed in relation to both as to generate E. M. F.'s in the conducting loops or coils on the armature. Such alternators are called *inductor alternators.*

CHAPTER IV.

POWER.

VISITING an electric central station at the time of full load, that is, when the station is generating its full electric power, it is evident that a great deal of energy is being expended or work being done. The fires under the boilers are working at full draft; the steam engines are working at full steam pressure and speed, and the dynamos, if belt-driven, are receiving practically all the energy liberated by the engines through their tightened connecting belts. Evidently, therefore, the *driving machinery* is transmitting an enormous amount of power to the *driven machinery*. Indeed, not infrequently several thousand horse-power are

thus delivered in large central stations, from the steam engines to the dynamos. But there is no immediate evidence to the eye, as to what becomes of all this power. Our everyday experience would lead us to expect some more evident effect produced by the expenditure of so much power. Were the engines suitably mounted on wheels and placed on a railroad track, the same amount of power applied to driving wheels would be sufficient to carry the entire plant along the road at a considerable speed. In the central station, however, the energy is transformed into electrical energy which is being silently carried away by the conductors. These silent conductors, however, are capable of delivering up the energy given to them at various points along their circuit, and if all this energy were employed to drive electric motors, the total work

which could be performed by such motors, provided no loss occurred in transmission, would of course be equal to that developed by the steam engines.

It is evident, then, that a circuit conveying an electric current, may, in its turn, be regarded as a source of driving power by which the motors are driven. But in the case of the steam engine, there is an evident connection between the driving and the driven dynamo; namely, the belting or shafting. There must also be some connection between the dynamo as a driving and the motor as the driven machine. Here the connection, though far less evident, consists in the conducting circuit connecting the dynamo and motor; or, in other words, the conducting circuit, and its electric activity, take the place of the driving belt.

Suppose a water motor is operated in a city by the flow of water through a pipe, connected with a reservoir on an adjoining hill. Here, clearly, the source of energy received by the motor is the moving or falling water. This energy, in its turn, was received from a pump which raised the water into the reservoir, from, possibly, a river or lake at a lower level. Moreover, the amount of energy received by the motor is perfectly definite, since each pound of water, falling from a height of one foot, conveys an amount of *work* called a *foot-pound*, so that, if the reservoir contains a million pounds of water, and the difference of level between the reservoir and the motor is 100 feet, then the total source of work upon which the motor can draw, is $100 \times 1,000,000$ or 100,000,000 foot-pounds.

This stock of power in the reservoir

might be expended by the water-motor in a day, or in an hour, according to the rate at which the motor works, and, therefore, permits the water to flow from the reservoir. In other words, the ability of the unreplenished reservoir to keep the motor running for a given time, depends upon what is called the *activity* of the motor, or the rate at which it is doing work. This activity is usually expressed in *foot-pounds per second*, or in *foot pounds per minute.*

The commercial unit of activity is the *horse-power*, or 550 foot-pounds per second. If, then, the motor be a one horse-power motor, and, for simplicity of calculation, be supposed to be a perfect machine; *i.e.*, to waste no power in friction, then the flow of water through the pipe will be 5 1-2 pounds per second, and this quantity of water falling one hundred feet

in one second will produce an activity of $5\ 1\text{-}2 \times 100 = 550$ foot-pounds per second.

Although electricity is not a liquid like water, yet, since many of the laws which control the flow of water are also applicable to the flow of electricity, it is convenient, in considering the manner in which an electric current is able to transmit power to a motor, to regard electricity as though it were a fluid in actual motion. As in the case of water in motion, the amount of activity transmitted can be expressed by the pounds of water flowing per second, multiplied by the difference of level in feet through which it flows, so in the case of an electric current, the activity transmitted can be expressed by the rate-of-flow of electricity in coulombs-per-second, multiplied by the difference of electric pressure

through which it flows, expressed in volts. Moreover, as the activity in the current of moving water is expressed in foot-pounds per second, of which 550 make a horse-power, so the activity in the current of electricity is expressed in *volt-coulombs per second*, or in *watts*, of which 746 make a horse-power. If, therefore, we multiply the rate of electric flow in a circuit, expressed in amperes, by the difference of electrical level or pressure, expressed in volts, the product will be the activity in the electrical circuit expressed in watts, 746 watts being equal to one horse-power.

The activity, or the rate of delivering power from a water reservoir, can be increased either by increasing the difference of level, or by increasing the rate-of-flow; so in an electric current, the activity, or the rate of delivering electric power, can

be increased either by increasing the difference of electrical level in volts, or by increasing the rate of electric flow in amperes.

Steam engines are generally rated in *horse-power* (contracted H.P.); that is to say, a one-horse-power steam engine is capable of doing an amount of work equal to 550 foot-pounds per second. A one-horse-power steam engine, therefore, is capable of lifting a pound weight 550 feet high, or 100 pounds 5 1-2 feet high, in each second of time.

Electric generators are usually rated in watts; but since a watt is so small a unit of activity, being only 1-746th of a horse-power, the *kilowatt* or 1000 watts is the unit generally adopted. Thus, a 1000-watt generator, or a 1 KW. generator, might supply one ampere in its circuit at

a pressure of 1000 volts, between its brushes; or, it might supply 50 amperes at a pressure of twenty volts, or 1000 amperes at a pressure of one volt.

The following examples of electrical activities, required for the operation of apparatus in common use, may prove of interest:

An ordinary incandescent lamp, of 16-candle-power, requires about 50 watts, so that at this rate one electrical horse-power will supply nearly fifteen lamps. The pressures at which such lamps are commonly operated are either about 100 volts or 50 volts. A 100-volt 16-candle-power lamp, will, therefore, usually take a current of approximately 1-2 ampere, since 100 volts × 1-2 ampere = 50 watts; while if the lamp be intended for a fifty-volt circuit, it will require a current of one am-

pere. An incandescent lamp, therefore, requires about 1-15th of a H.P. or about 37 foot-pounds per second to be supplied to it at its terminals in electrical energy.

An arc lamp, of the ordinary 2000 candle-power rating, usually requires some 450 watts for the production of the arc at a pressure of 45 volts. This represents a current strength of 10 amperes, since 45 volts $\times$ 10 amperes = 450 watts. An arc lamp, therefore, requires to be supplied with an activity of about 3-5ths of an electrical horse-power; or, in other words, for every arc lamp supplied to a circuit, the engine driving the arc light generator must supply 3-5ths of a horse-power, and something over for losses in transmission.

An electric current of 5000 amperes, supplied from a central station to a net-

work of trolley conductors, in a street railway system, under a pressure of 550 volts at the dynamo brushes, will represent a total activity of $550 \times 5000 = 2,750,000$ watts, or 2750 KW. or 3686 H. P. in electrical energy supplied to conductors.

Although, as we have seen, the rate of work or activity, in a continuous current, is equal to the number of amperes multiplied by the number of volts, yet when we come to apply the same rule to the case of alternating currents, we find that it is only true under certain circumstances.

This is for the reason that, in the continuous-current circuit, the pressure is always acting to drive the current in the direction in which it is already moving, while in an alternating-current circuit it may be at times aiding the current for-

ward, and at times opposing it. Fig. 24 represents the current strength in an alternating-current circuit, and also the E. M. F. of the generator by which that cur-

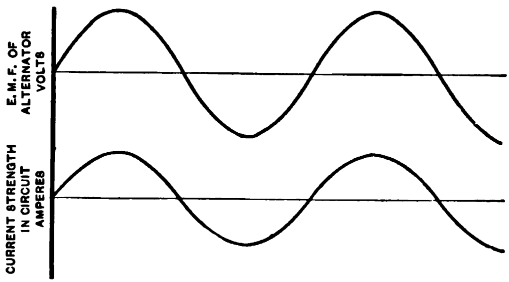


FIG. 24.—WAVES OF ALTERNATING E. M. F. AND CURRENT IN STEP.

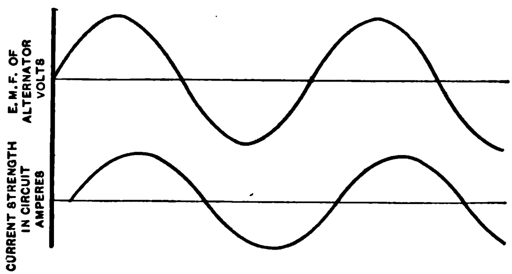


FIG. 25.—WAVES OF ALTERNATING E. M. F. AND CURRENT IN A CIRCUIT, OUT OF STEP.

rent strength is produced. The two sets of waves are seen to be in step, the crests of the E. M. F. waves coinciding with the crest of the current waves. In such a case the product of the effective volts and the effective amperes gives the electric activity, just as in the case of a continuous-current circuit. Fig. 25, however, represents the more usual case in which the pressure or E. M. F. is in advance of the current. It will be observed that at the moment when the pressure has its greatest value, or rises to the crest of its wave, the current strength will not have reached the crest of its wave, the result will be that the pressure will have dropped below the zero line 00, or will have become negative, while the current is still above the zero line, or in the positive direction. In other words, the pressure or E. M. F., instead of aiding the current at this in-

stant, is opposing it. Under these circumstances if we multiply the effective, number of volts by the effective number of amperes, we shall obtain an activity which is greater than that actually produced in the circuit. In other words, the *apparent activity* in watts will be greater than the actual activity in watts, and the discrepancy will depend upon the distances between the crests of the pressure and current waves; *i. e.*, upon the amount of time, in each period, during which the pressure is opposing, instead of driving. The apparent activity, has, therefore, to be multiplied by a quantity called the *power factor*, in order to obtain the real activity. The value of the power factor depends upon the difference of phase. The waves of current and pressure are said to be *in phase*, or *in step*, when their crests and troughs occur simultaneously;

and when the waves of pressure become separated from the waves of current, the two waves are said to differ in phase.

Even in an alternating-current circuit, under certain circumstances, if we take for both of these quantities their effective values, as we have heretofore pointed out, the activity is correctly represented by the product of the E. M. F. by the current. This would be the case in a circuit of incandescent lamps where the circuit is practically free from loops, since, in such a circuit, induction is practically absent. Such a circuit is sometimes called an *inductionless circuit;* but when, as is the case in most practical alternating-current circuits, conducting loops, in the shape of coils of wire, are present, then, as we have already pointed out, the successive filling and emptying of these loops with magnetic flux,

on the rapid periodical increase and decrease in current strength, will set up E. M. F.'s in the wire, counter or opposed to the E. M. F.'s producing such flux, so that the combined effect of the impressed and the counter E. M. F.'s produces what is called a *resultant* E. M. F. which is shifted in position, or differs in amount and phase from the impressed E. M. F. But with this resultant E. M. F. the current is always in step. This resultant E. M. F., multiplied by the current in step with it, gives the true activity of the current. Since, however, the circumstances producing the displacement of the current, in phase, are often complex, it is well to multiply the impressed E. M. F. by the current and introduce a power factor rather than to determine what the resultant E. M. F. in the circuit may be. For example, an incandescent lamp, supplied direct from

mains at an alternating pressure of 100 volts, may take, say half an ampere of current. The activity in the lamp will be $100 \times 1\text{-}2 = 50$ watts, and the power factor is one, or 100 per cent. This is for the reason that there is no reactance in the lamp, and the current waves through its filament are almost exactly in step with the waves of pressure at its terminals. Consequently, the activity of the lamp, and the light it emits, will be the same, whether it be connected to 100 volts alternating or continuous pressure.

If, however, the same alternating-current mains be connected with a coil of many turns, the resistance of which is the same as that of the lamp filament, while the continuous current will be half an ampere as before, the alternating current will be much less, perhaps, only 1-10th

of an ampere, this being due to the reactance of the coil, as already explained. The activity in the continuous current will be 50 watts, but in the alternating current it will not be 100 × 1-10th or 10 watts, but considerably less, because the waves of pressure and current, owing to the reactance of the coil, are out of phase, and the power factor of the coil will be less than say 30 per cent., making an electrical activity in the coil only 10 × 30-100ths = 3 watts.

CHAPTER V.

TRANSFORMERS.

If we leave the central station and follow an alternating-current circuit, erected upon poles, up to the first point where the current is utilized, we will probably see apparatus of the general type represented in Fig. 26, either placed upon a pole, as shown in the figure, or in some convenient location on the side of a building. Such an apparatus is called a *transformer*, and is only employed on alternating-current circuits. It remains now to examine the general construction of alternating-current transformers, and the part they take in the economical distribution of electric currents over extended areas.

If an alternator, at a central station, is

supplying 100 volts at its collector rings, a 100-volt lamp connected at the brushes of such a machine will burn at full incandes-

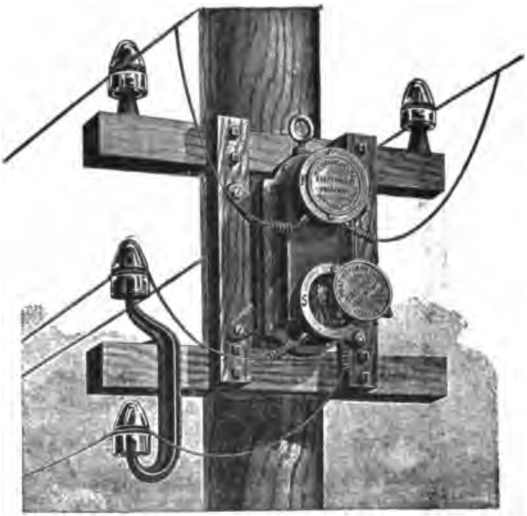


FIG. 26.—ALTERNATING-CURRENT TRANSFORMER WITH DIRECT SERVICE WIRES.

cence or brilliancy. Suppose, now, that this alternator be connected to a pair of wires five miles in length. If the lamps were

connected to the lines as shown in Fig. 27, at distances of 1, 2, 3, 4 and 5 miles respectively, we should find that the brilliancy of the lamps diminished as the distance from the alternator increased; the reason being that the pressure, or voltage, between the lines at the lamp terminals, would decrease as we receded from the

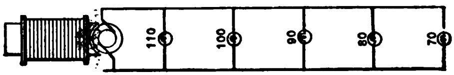


FIG. 27.—DIAGRAM ILLUSTRATING THE FALL OF ELECTRIC PRESSURE OR VOLTAGE ALONG A CIRCUIT.

alternator. This decrease in pressure of electricity flowing from an alternator, through a long conductor, finds its analogue in the decrease of the pressure of water flowing from a reservoir through a long pipe as shown in Fig. 28. If the reservoir supply water through a pipe, and pressure gauges be connected at different distances, say 1, 2, 3, 4 and 5 miles.

as shown, then, when the flow is entirely shut off at the distant end, assuming no leakage through the pipe, the gauges will all show the same pressure; but when the flow is fully established through the pipe, the gauge at the outflow, where the wa-

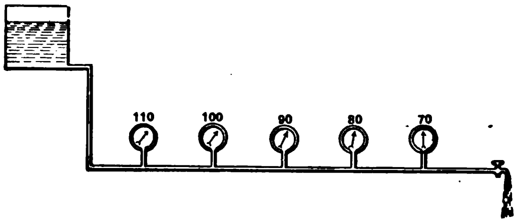


FIG. 28.—DIAGRAM ILLUSTRATING THE FALL OF HYDRAULIC PRESSURE ALONG AN OUTFLOW PIPE.

ter escapes, will, owing to the loss of head, or drop of pressure, arising from the friction of the water in the pipe, show the lowest pressure. The pressure at intermediate distances between the reservoir and the outflow, will be intermediate between the pressure at the reservoir and

the pressure at the outflow. Similarly, in an electric circuit, the resistance offered by the conductors to an electric flow produces a *drop of pressure*, so that under the conditions shown, the most distant lamps will only receive say 70 volts, while the intermediate lamps will receive pressures intermediate between 110 and 70 volts. The fall of pressure depends on the size of the wire and the strength of the current required for each lamp.

An ordinary incandescent lamp of 16-candle-power requires to be supplied, as already stated, with an activity of about 50 watts. Since, in the preceding case, the pressure is assumed to be 100 volts, each lamp would take approximately 1·2 ampere of current (100 volts × 1·2 ampere = 50 watts). If the lamp could be constructed so that it would properly operate when

supplied with say 1-20th of an ampere, or 10 times less current, the current supplied by an alternator to such lamps, under similar conditions, would be 10 times less, and the drop of pressure in the mains would, therefore, be 10 times less, since the drop of pressure in any conductor, expressed in volts, is always equal to the current which it carries in amperes multiplied by its resistance in ohms. But such a 50-watt lamp, taking only 1-20th ampere, would have to be designed for a pressure of 1000 volts (1000 volts × 1-20th ampere = 50 watts). Such lamps can not be conveniently made at the present time, and even if they could be made, 1000 volts is an unsafe alternating-electric pressure to introduce into a building. The only way in which this troublesome drop of pressure can be avoided, without the use of special apparatus, when the best arrangement of

wires has been adopted for the distribution of light, is to decrease one of the factors on which the value of the drop depends; namely, to decrease the resistance of the wires, by increasing their size and weight. In other words, we can always decrease the drop indefinitely, by increasing the size of the conductors indefinitely. But heavy conductors of copper are expensive, and a point is soon reached when the distance, to which electric supply can be carried from a central station to lamps, is commercially impossible.

Happily, however, the use of transformers with alternating currents renders it possible to obtain all the advantages of high-pressure transmission and yet readily to reduce such pressure to 50 or 100 volts within the building it is desired to supply. The corresponding conditions of

hydraulic transmission are represented in Fig. 29 where a long pipe, *PP*, of small cross-section, carries water from a reservoir *R*, at a high pressure and enters the

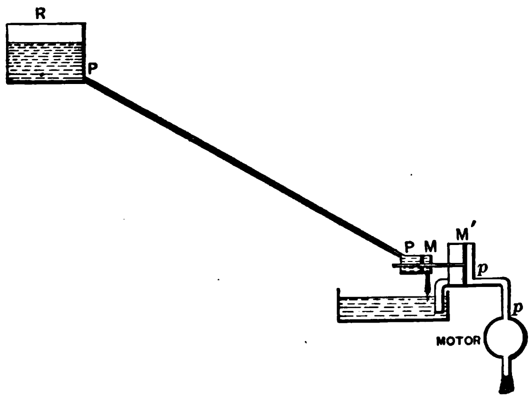


FIG. 29.—DIAGRAM REPRESENTING LONG DISTANCE WATER POWER TRANSMISSION THROUGH SMALL PIPE AT HIGH PRESSURE, WITH TRANSFORMATION TO LARGE PIPE, LOW PRESSURE, LOCAL SYSTEM.

high-pressure cylinder of a pump *M*, connected with a large, low-pressure cylinder of the pump *M*, which drives forward a large quantity of water from a local reser-

voir at a reduced pressure, through a large pipe *p p*, to the water motor in its vicinity. By such an arrangement, therefore, it is possible to transmit water power to a great distance by a small pipe, and yet deliver a large volume of water to a motor which is designed to be operated at a low pressure. In the same way, by the use of alternating currents in connection with transformers, it is possible to obtain all the advantages to be derived from the transmission of high pressure electric currents over small wires, and yet so transform or change the pressure at the point cf consumption as to permit the use of incandescent lamps that will only operate economically under low pressures.

It has already been pointed out that the value of the electrical activity transmitted by any circuit when the power factor is

100 per cent. or unity, is equal to the product of the amperes multiplied by the volts, and it is clear that a small electric current, carried at a high pressure, say 10 amperes at 1000 volts, would give the same amount of activity, namely, 10 KW., as would a current of 100 amperes at 100 volts, but would require a much smaller wire.

An *alternating-current transformer* is a device for enabling electric energy to be economically transmitted at high pressure and low current strength, to the point of delivery, and then reducing or transforming this supply to a large current at a correspondingly lower pressure.

Let us inquire into the means whereby a transformer is capable of performing this important function. To do this we will first examine its construction. The

alternating-current transformer consists essentially of two coils of wire, one usually coarse and the other fine, the fine wire coil being of much greater length and having a greater number of turns than the coarse wire. Fig. 30 shows one of the simplest forms of transformers. It consists, as shown, of two coils of wire *P* and *S*, wound on a core of iron wire. When an alternating current is sent through coil *P*, called the *primary coil*, it will, by induction, produce an alternating E. M. F., of the same frequency, in the coil *S*, which

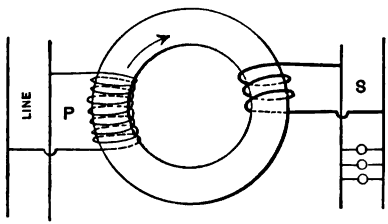


FIG. 30. — SIMPLE FORM OF ALTERNATING-CURRENT TRANSFORMER.

is called the *secondary coil*, and this secondary E. M. F. is employed to send an alternating current through the lamps or other apparatus which are to be operated. In the case supposed, the high-pressure current would be sent through the primary coil *P*, whose terminals are connected to the line, and the low-pressure current would be induced in the secondary coil *S*, whose terminals are connected as shown with the apparatus to be operated.

The alternating-current transformer operates as follows: On the passage of the alternating current through the primary coil *P*, the coil become alternately magnetized in opposite directions; that is to say, its loops become successively filled and emptied with an oscillating magnetic flux. The coil thereby has a counter E. M. F. set up in it, or, in other

words, acts as a choking coil. At the same time, the flux through the iron core successively fills and empties the secondary coil *S*, and thereby induces in it an E. M. F. which will alternate at the same frequency as that in the primary. If the circuit of the secondary coil is *open; i. e.*, disconnected from its apparatus, the presence of this secondary E. M. F. will not affect the reactance or choking effect of the primary coil; but if, on the contrary, the secondary circuit be *closed* through its load of lamps, motors, or other apparatus, the current in the secondary coil will tend to magnetize the core in the opposite direction to that of the primary coil, and so diminish the reactance of the primary winding. The choking effect of the primary coil will, thereby, be reduced as the secondary current and the load increase. In other words, the transformer

becomes *self-regulating*, the choking effects of the primary coil automatically varying so as to permit the right amount of current and power to be received from the high pressure mains, in order adequately to supply the secondary or low pressure consumption circuit.

Let us now examine the pressures which exist in the primary and secondary circuits. If each coil P and S, has the same number of turns, the E. M. F. induced in the secondary will be practically the same as that supplied or impressed upon the terminals of the primary, so that there would be no transformation or change as regards pressure and current. If, however, the secondary coil is made up of but half the number of turns in the primary coil, the flux passing through the iron core only links with half the number

of secondary turns that it links with in the primary coil, and the E. M. F. induced in the secondary will be but half as great as that in the primary. If the primary impressed E. M. F. were 1000 volts effective, that in the secondary circuit would be about 500 volts. Again, if the secondary coil contain say one tenth of the number of turns existing in the primary coil, then its E. M. F. would be correspondingly reduced and would become approximately 100 volts. If in this case the wire forming the secondary coil were maintained of the same diameter as that in the primary coil, the small secondary coil would, for the same electrical activity in each circuit, have to carry ten times the current strength which is supplied to the primary. It would be necessary, therefore, to increase the cross-section of the secondary coil, say ten

times, so that the bulk of the two will, in practice, be approximately the same.

It is evident that if the coil S, assumed in the last condition to contain one tenth of the number of turns in the coil P, could be connected to the high-pressure terminals, or, in other words, be employed as the primary, that the coil P, would have an E. M. F. induced in it, whose value would be ten times as great as that in the mains. Transformers may, therefore, be divided into two sharply-marked classes; namely, *step-down transformers*, where the pressure in the secondary is less than the primary pressure, and *step-up transformers*, where the pressure in the secondary is greater than the primary pressure. In actual practice, transformers are not built in the exact manner shown in the last figure. The primary and secondary coils

may be variously disposed as regards each other, but in all cases they are brought as close together as possible, and are so surrounded by laminated iron as to cause the flux produced by the primary to pass through or become linked with all the turns of the secondary. Since the coils may assume various positions, it is evident that different types of transformers may differ radically in their appearance. They will, however, all possess the same essential features; namely, primary and secondary coils, and a laminated iron core common to both.

Fig. 31 represents a laminated iron core *C*, of sheet iron stampings, having a form resembling that shown in Fig. 32, within the hollow spaces of which are inserted the two coils *P* and *S*, one being the primary coil of say 1000 turns of fine wire, and the

other the secondary coil (for convenience divided into halves) with a total of say 100 turns of coarser wire. Since the primary coil may be connected to mains at say 1000 volts pressure, and is in close juxtaposition to the secondary coil, from which wires are carried into the building to be

FIG. 31.—TRANSFORMER SHOWING INTERNAL CONSTRUCTION.

supplied by the current, it is evident that the insulation of the two coils from each other must be carefully preserved, since, otherwise, the pressure of 1000 volts might be led into the building. In order to ensure a high degree of insulation, the coils are sometimes immersed in an insulating

oil. The transformer coils shown in Fig. 31 at *A*, are placed in the iron vessel shown at *B*, which is then filled with oil.

Another form of *oil-insulated, step-down transformer* is shown in Fig. 33. Here the

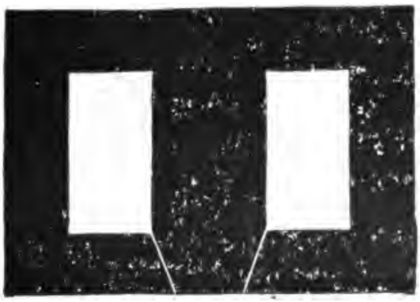


Fig. 32.—Sheet Iron Stamping. For Transformer Shown in Fig. 31.

primary coil has its ends brought out at *p*, *p*, and its secondaries at *s*, *s*, divided, as before, into two halves for convenience. This transformer is enclosed as shown in Fig. 34, in a box filled with oil, the pri-

mary terminals being brought out through the fuse-box at *P* and *P*, and the secondary terminals at *S* and *S*.

In order to prevent the current gener-

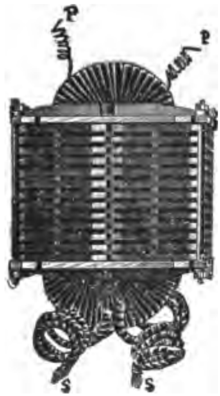


FIG. 33.—100-LIGHT TRANSFORMER WITHOUT BOX.

ated in the secondary circuit from becoming dangerously great, should an accidental short-circuit occur in the wires of the

building supplied, a device called a *fuse-block* is employed with transformers. This device consists of an iron box containing lead fuse wires which are inserted

Fig. 34.—100-Light Standard Transformer.

in the primary circuit, so that the current from the high-pressure mains, in order to reach the primary coil, has to pass through these fuse wires. The fuse wires

are composed of a lead alloy of such size that they carry safely the normal working current of the transformer, but, on an undue excess of current, become so heated as to melt, and open the circuit, thus automatically disconnecting the transformer from the mains. The porce-

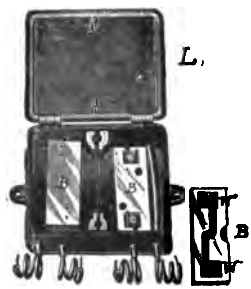


FIG. 35.—FUSE-BOX AND FUSES.

lain or earthenware fuse-block is shown in Fig. 35 at B, with a fuse wire WW, laid across it, having its ends clamped under connection screws. The box is

provided with the lid *L*, so that when the fuses have been melted or "*blown*" new wires can be readily inserted.

Another form of *transformer fuse-box* is

FIG. 36.—DETAILS OF TRANSFORMER FUSE-BOX.

shown in Fig. 36, detached from its transformer case. Here, two unglazed porcelain handles *H*, *H*, are inserted by hand into two separate porcelain apartments in an iron box. Within these compartments

are brass contact pieces, only one of which S_1, is visible in the figure, so arranged that when the handle *H*, *H*, is pressed home into the compartment, connection is maintained between them through the fuse wires, *W*, *W*, clamped between binding posts *T*, *T*, and connected with flexible plugs *S*, *S*, which fit into the receptacles S_1. The lid *L*, is provided for closing the box. The advantage of this particular form is that when the handles are pushed in, thus connecting the transformer with the high-pressure mains *P*, *P*, the sudden or explosive fusing of the wire cannot injure the operator, whose hand is protected by the back of the handle *H*.

Fuse wires are also inserted in the secondary circuits of the transformer, sometimes in the transformer itself as at *S*, in Fig. 26, and, sometimes, in separate fuse-boxes within the building.

We have seen in Figs. 31, 33 and 34, that the secondary coils are divided into two separate halves. The advantage of this method lies in the fact that some houses have their lamp circuits wired for 50 volts pressure, and others for 100 volts pressure. If now, the coils of each of the two separate circuits of such a transformer, having a pressure of 50 volts, are so arranged that the current passes from one secondary coil through the next in succession, so that the two coils are connected as though they formed an unbroken winding, then their E. M. F.'s will be added, making a total of 100 volts. On the contrary, if it be desired to use a pressure of but 50 volts, then the two coils are employed side by side, or so connected to the house wires that each of the coils supplies half the current delivered. Such connections are shown in Fig. 37.

At *A*, 100 volts are obtained for the secondary circuit by connecting the two coils *in series*, as it is called, so that the arrows represent the direction of the current at some particular instant. At *B*,

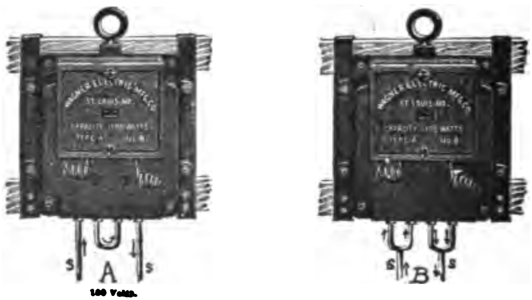


FIG. 37.—METHOD OF CHANGING SECONDARY CONNECTIONS.

50 volts are obtained by the *parallel* connection of two coils, or, as it is sometimes called, by their connection *in multiple*. If at *A*, the transformer is delivering 10 amperes at 100 volts pressure, or 1000 watts, at *B*, it will be delivering 10 amperes in

each coil, or 20 amperes in all, at 50 volts pressure, and, therefore, also 1000 watts.

In Fig. 31. the capacity of the transformer represented is 600 watts, or such as is capable of furnishing current for operating 12 fifty-watt lamps. That in Figs. 33 and 34, 5000 watts, or 100 such lamps.

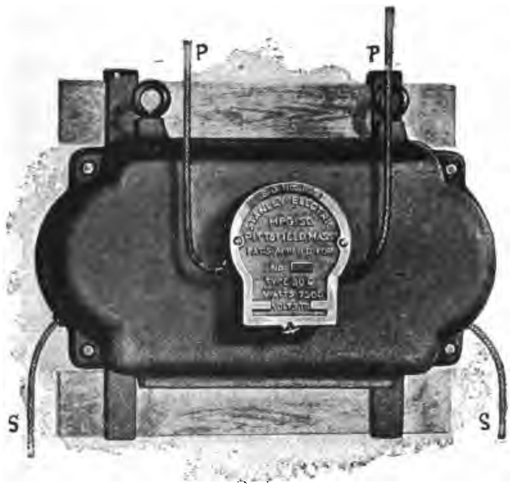


FIG. 38.—OUTDOOR TYPE OF TRANSFORMER.

A still larger transformer of 7500 watts capacity, or capable of operating 150 fifty-watt lamps, is represented in Fig. 38. This particular transformer is not insulated with oil, but depends upon the insulating covering of its coils for protection, the free space within the cover or iron shield being filled with air.

The current required to supply a transformer at full load may readily be ascertained when the primary pressure is known. For example, in the case of a 7500-watt transformer, if the primary pressure is 1000 volts, the primary current must be 7 1-2 amperes (1000 volts × 7 1-2 amperes = 7500 watts), if we assume that the *primary power factor* is 100 per cent. and that no loss occurs in the transformer. Strictly speaking, the power factor, even at full load, is not quite 100 per

cent., and a little loss of energy occurs in the transformer; *i.e.*, the transformer becomes warm in doing its work, so that the current strength supplied from the primary circuit at full load must be somewhat in excess of 7 1-2 amperes.

FIG. 39.—500-LIGHT TRANSFORMER, INDOOR TYPE.

A form of 25,000-watt transformer (25 KW. or about 33 H. P.) intended for 500 fifty-watt, 16-candle-power incandescent lamps, is represented in Fig. 39. This transformer is intended to be located in a cellar, or other suitable place within doors.

It will be seen that as the capacity of the transformer increases; *i. e.*, as the transformer has to supply more and more power, its dimensions increase, but not in the same proportion as the increase in capacity; so that if a 1 KW. or 20-light transformer weighs, in its case complete, 140 pounds, or gives 7 watts per pound of total weight, a 25 KW. transformer will, probably, weigh only 2000 pounds, or give 12 1-2 watts per pound, while a 200 KW. transformer will, perhaps, give 25 watts per pound, and a 1200 KW. transformer 100 watts per pound. It is much cheaper, per kilowatt of output, to construct transformers in large sizes.

When a step-down transformer is employed to reduce the pressure in a building from 1000 to 100 volts, it is clear that at the central station supplying the mains

leading to the building a generator must be employed of 1000 volts E. M. F. or more. This is commonly the case, and alternating-current generators in the U. S. generally produce either about 1000 or 2000 volts effective at their terminals. When, however, the current has to be transmitted over lines of great length, and it is necessary, for purposes of economy in conductors, to employ much higher pressures, say 10,000 volts, it is desirable, both on the score of safety and economy, to employ a step-up transformer, supplied by the generator at a lower pressure, rather than to endeavor to construct a generator to directly develop such pressure. In such cases, of course, these step-up transformers would be connected directly to the alternator terminals.

Large step-down transformers, intended

to supply an extended system of mains, are frequently installed in a small sub-station, for which reason they are sometimes

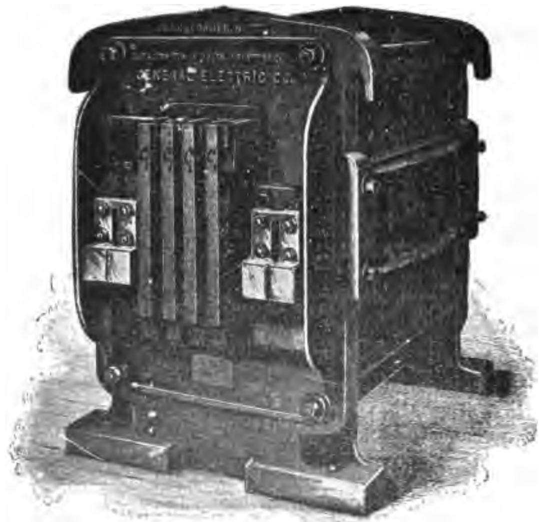


FIG. 40.—SUB-STATION TRANSFORMER.

called *sub-station transformers.* Since such transformers may take the entire load of a large alternator, they necessarily re-

quire to be of considerable dimensions. A form of such transformer is shown in Fig. 40, its length being about 6 feet. In designing such transformers care is taken to provide for the dissipation of the heat generated in their iron core and conductors when in action. Here the laminated core, consisting of large, thin sheets of iron, forming the frame or body of the apparatus, *CC*, is closely linked with the coils, *c*, *c*, *c*, *c*. The whole apparatus is carefully ventilated to permit of the free access of air and the insulation of the coils carefully preserved by means of sheets of mica.

Another advantage secured by the use of a few large transformers in place of a number of smaller ones is a greater efficiency. A large transformer in the course of its daily duty will probably supply, to its secondary circuit, 96 per cent. of the energy it receives at its primary terminal,

only 4 per cent. being lost in the transformers. The same amount of power being distributed by a number of small transformers might perhaps result on the average to a delivery of 80 per cent. and a loss of 20 per cent. In other words a small transformer wastes proportionately more energy than a large one.

CHAPTER VI.

ELECTRIC LAMPS.

HAVING examined in the previous chapters the method of generating alternating currents, the means employed for their distribution, and the apparatus by which their strength can be varied, it remains to discuss some of the different types of electric apparatus to which such currents are supplied. These are of a variety of forms, but the most important, at the present time, are lamps and motors.

When an electric current is sent through a conductor of high-resistance and small cross-section, so that a considerable amount of electric energy is expended in a small mass of material, the conductor is

heated, perhaps, to the temperature of luminosity, when it will emit light and heat. This is the principle on which an incandescent electric lamp is operated; a short thin filament or thread of carbon forming the high-resistance conductor.

The carbon filament acquires its high temperature in a fraction of a second after the current has been sent through it, as can be determined by observing the time which elapses from the closing of the circuit by turning the key or switch of an incandescent lamp until the lamp gains its full incandescence. In the same manner, on the interruption of the current by the opening of the circuit, an equally short time is required for the lamp to lose its brilliancy especially in slender filaments.

In an alternating-current circuit, the current not only changes its strength but

also changes its direction, during the different parts of an alternation. Consequently, twice in each cycle, at the moment when the change of direction occurs, there can be no current in the circuit, as will be evident from an inspection of Fig. 6. When alternating currents are supplied to incandescent lamps at a frequency of 100 cycles per second, it is evident that 200 times in each second there is no current passing through the lamp. It might, therefore, be supposed that the lamp would go out and be relighted 200 times a second. In reality an incandescent lamp tends to do this, and would do it were it not for the fact that the intervals of cessation of current are so brief that the lamp has not sufficient time in which to appreciably cool down, so that such changes of temperature as do occur, are not visible to the eye, and the lamp does

not visibly flicker. In order, however, to obtain this absence of flickering a certain frequency of alternation is necessary; for, it is evident that if the frequency becomes very low, sufficient time will elapse, between the current waves, to permit the carbon to sensibly decrease in brightness, thus permitting the retina of the eye to retain the impression of flickering. It has been found, in practice, that flickering in an incandescent lamp does not occur when the frequency of the alternation exceeds 30 to 35 cycles per second. In practice, in the United States, alternators for incandescent lighting are usually designed to produce a frequency much higher, say from 125 to 135 cycles per second.

When the energy from an electric current is utilized in an incandescent lamp, by far the greater part is uselessly ex-

pended in producing heat, or *non-luminous radiation.* It has been found that a comparatively slight increase in temperature will cause a marked increase in the amount of light emitted by a glowing filament. Consequently, the *commercial efficiency* of a lamp that is its ability to convert electrical energy into light energy,will be greatly increased, by any circumstance which will safely permit of an increase of temperature of its filament. This can readily be shown by applying successively increasing pressure or voltage to the terminals of a lamp, and so causing greater current to flow through it, the increase in the current being followed by a marked increase in the amount of light given off. Were it possible to double the ordinary working temperature of the filament of an incandescent lamp, without destroying it, we would very markedly in-

cease its light-giving power. In point of fact even a slight increase above the ordinary temperature produces a great increase in the brilliancy of the lamp.

But while an improvement is thus obtained in the light-giving power of a lamp, the *life of the lamp*, or the number of hours during which it will continue to give out this light, is greatly diminished. The problem for increasing the efficiency of an incandescent lamp has, therefore, been to obtain a conducting substance which would continuously stand a high temperature. Carbon is the only substance which has, thus far, been found available for commercial use. There is a certain temperature at which it is found most economical to operate carbon filaments, both in regard to their amount of light and duration of life. Below this tem-

perature, while the life greatly increases, the candle-power rapidly falls off. An incandescent lamp, burning at dull red temperature, will have an indefinitely long lifetime, while a similar lamp, operated at the ordinary temperatures commercially employed, will burn from 600 to 1800 hours.

Since the filaments of incandescent lamps are made of various lengths and cross-sections, or, in other words, since their filaments have varying electrical resistances, the pressures required to produce in them the requisite temperature will necessarily vary. In practice, lamps are constructed which require pressures varying from 2 volts to 250 volts. *High-pressure lamps*, of any given candle-power, have long, thin filaments, while *low-pressure lamps*, of the same candle-power, have short thick filaments.

Various forms are given to incandescent lamps, but all consist essentially of the same parts; namely, an *incandescing filament* of carbon placed in an exhausted *glass chamber* and connected with the cir-

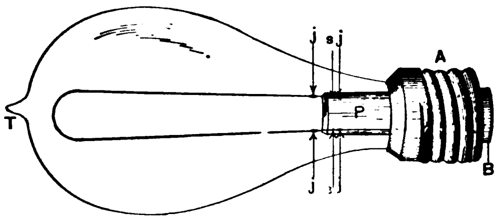


FIG. 41.—16-C.P. INCANDESCENT LAMP.

cuit by a *socket*, the wires leading the current into the lamp being automatically connected with the circuit by the act of inserting the lamp in its socket.

Some forms of incandescent lamps are shown in Figs. 41, 42, 43 and 44. Fig. 41 is a form of 16-candle-power lamp in extensive use, consisting of a filament bent in a

single loop. The *lamp base* is provided with a screw thread for insertion in the

FIG. 42.—INCANDESCENT LAMPS AND SOCKET.

screw socket. Fig. 42 represents another form of lamp, in which the screw thread is

FIG. 43.—INCANDESCENT LAMPS.

in the interior of the base, instead of on the external surface. This figure

also shows a lamp inserted in the socket which is provided with a key K. Figs. 43 and 44 show another form of incandescent

FIG. 44.—INCANDESCENT LAMPS.

lamp furnished with different bases; *a* is intended to give 10 candle-power, *b*, 16 candle-power, *c*, 20 and *d*, 32.

All the incandescent lamps here shown are equally applicable for use on continuous or alternating-current circuits. In practice, where the area of distribution to consumers is not great, the continuous current is usually employed, but where the area of distribution is large, and the lighting scattered, it is usually more economical to use alternating currents in connection with step-down transformers.

Incandescent lamps as supplied from step-down transformers are always connected *in parallel*, that is, the lamp's terminals are connected across the mains as shown in Fig. 45, which represents a *two-wire system of distribution.* Sometimes,

however, the lamps are connected as shown in Fig. 46, where the 20 lamps shown are connected between three wires of the *three-wire system of distribution* represented.

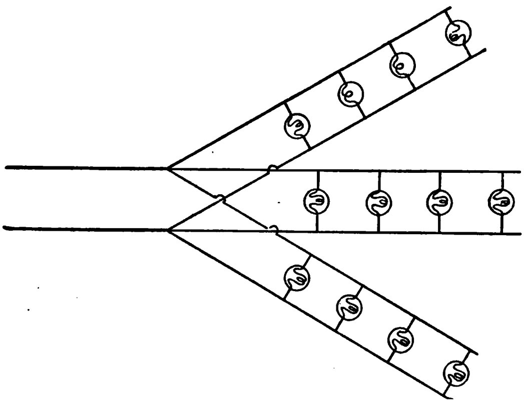


FIG. 45.—TWO-WIRE SYSTEM OF MULTIPLE CONNECTED LAMPS.

In cases, however, where incandescent lamps are required for street lighting over an extended area, where the lights are, therefore, scattered, the systems of dis-

tribution shown in Figs. 45 and 46, are too expensive, and it is also too expensive to employ a special or separate transformer for each lamp post. In this case the method of distribution sometimes

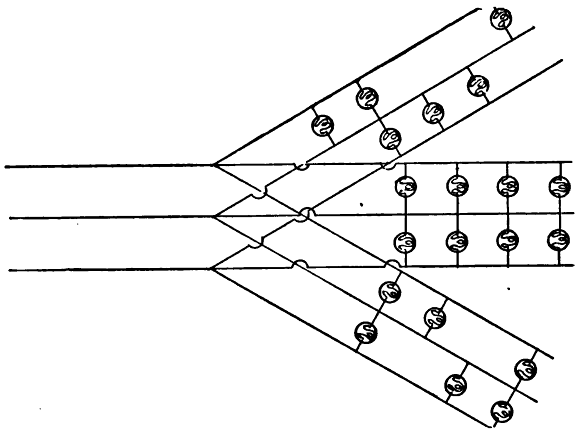


FIG. 46.—THREE-WIRE SYSTEM OF MULTIPLE CONNECTED LAMPS.

employed is that represented in Fig. 47, where the lamps are connected *in series*, the current passing successively through

each lamp. In the method of distribution shown in Figs. 45 and 46, the failure of any one of the lamps to operate, as, for example, by the breaking of its filament,

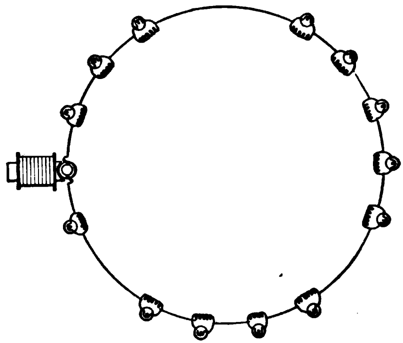


FIG. 47.—SERIES DISTRIBUTION OF INCANDESCENT LAMPS WITH ALTERNATING CURRENTS.

does not affect the supply of current to the other lamps. When, however, the lamps are connected in series, the discontinuity of one lamp would open the entire circuit were it not for the small *choking*

coil which is placed as a shunt or by-path to each lamp. While the circuit is maintained through the lamps, very little current passes through the choking coil, so that the waste of current and energy through the latter is very small. If, however, the lamp breaks its circuit, the choking coil carries the current without appreciably affecting the supply to the rest of the lamps in the circuit. These choking coils are represented in Fig. 47 as being connected around the terminals of each lamp. Fig. 48 represents such a street lamp with its choking coil. Here the lamp is provided with an external shade and globe to protect it from the weather. Fig. 49 gives a more complete view of the choking coil.

Alternating currents are also employed for arc lighting. As in the case of incan-

descent lighting, in order to prevent the variations in the current strength from producing marked flickering in the light, a certain frequency is necessary. It has been found in practice that the arc lamps

FIG. 48.—COMBINED FIXTURE AND REACTIVE COIL.

will show no disagreeable flickering if the frequency exceeds 45 cycles per second.

Alternating-current arc lamps do not differ in general construction from continuous-current arc lamps, save in the details

of their regulating mechanism. Since, however, the upper and lower carbons be-

FIG. 49.—STREET LAMP REACTIVE COIL.

come alternately positive and negative, the rate of consumption of each carbon is sensibly the same. A form of arc lamp,

FIG. 50.—ALTERNATING-CURRENT ARC LAMP.

suitable for use for an alternating-incandescent circuit of either 50 or 100 volts pressure, is shown in Fig. 50. In circuit

FIG. 51.—REACTIVE COIL OR COMPENSATOR FOR ARC LAMPS ON ALTERNATING-CURRENT CIRCUIT.

with the lamp or lamps is connected a choking coil or *compensator*, as shown in Fig. 49, whose object is to regulate automatically the amount of current passing through the lamp.

CHAPTER VII.

ELECTRIC MOTORS.

It is a well-known fact that when a continuous electric current passes through a continuous-current generator at rest, the generator will be set in motion. The early history of this discovery still remains in some doubt. It is claimed that the first observation of this power of a dynamo to act as a motor, or, in other words, this *reversibility of the dynamo*, was the result of an accident, which occurred during the Vienna Exhibition of 1873, when the current of one generator was accidentally led through the circuit of a second generator. According to, perhaps, more credible accounts, this property was the direct result of research in 1867. However this

may be, the first dynamo that was ever publicly exhibited running as a motor, from the current supplied by a similar dynamo, was at the opening of the 1873 Vienna Exhibition.

It is a well-recognized scientific principle that work is never lost or. in other words, that the total amount of energy existing in the universe is constant. Work may be made to assume different forms, but can never be annihilated. When, for example, mechanical work is expended in driving a dynamo, apart from certain expenditures, all this work is transformed into electrical work. When this electrical work is properly applied to the armature of another generator standing at rest, the electrical work is transformed into mechanical work, as is evidenced by the ability of the motor to drive machinery. We

have seen that a horse-power is equal to an activity of 746 watts. Consequently, if the electric motor were a perfect machine; *i. e.*, wasted no power, it would take 746 watts, from the circuit supplying it, for every horse-power it exerted in its work; and, if operated at a pressure of 100 volts at the mains, would, therefore, receive 746-100=7.46 amperes, per horse-power delivered. Owing to the necessary losses of energy in the motor, a greater current strength than this will in practice be needed, perhaps, 10 amperes, depending, however, upon the size of the motors. Large electric motors frequently possess a very high *efficiency; i. e.*, their *output* in mechanical work is very nearly equal to their *intake* in electrical work. Since, as we have seen, a motor can readily be driven at a long distance from the generator supplying it, is evident that the *elec-*

trical transmission of power possesses marked advantages. An example of a continuous-current motor is shown at Fig. 52.

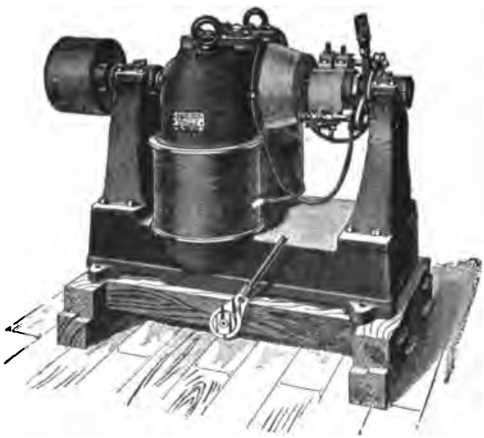


FIG. 52.—CONTINUOUS-CURRENT STATIONARY MOTOR.

If two continuous-current generators, similar in all respects, be electrically connected by a circuit say one mile in length, one being driven by a steam engine as a generator, while the other is

running at the same speed as a motor, then, as we have already seen, the current is alternating in the armature of each machine, but, owing to the action of the commutator, is continuous in the line between them. Assuming the two machines to be running at the same speed, if the commutators are suddenly removed from each, the two machines will continue running, though the current on the line, as well as the current through the armatures, will now be alternating. The two machines, which must now be regarded as alternating-current machines, will still be acting as generator and motor, cr as the driving and the driven machine.

In this respect, therefore, continuous and alternating-current dynamos are alike; since, in either case, one acting as the generator can drive the other as the

motor. They differ, however, in this respect, that, whereas, in the case of the continuous-current circuit, the motor will start from a state of rest, and can be driven either at the same speed as the generator or at different speeds; in the case of the alternating-current circuit, the motor will not start from a state of rest and can not be operated until it has been brought up to the same speed as the generator; or, as it is usually termed, until it has been brought *into step* with it. Once the motor has been brought up to the speed of the generator, it can, if well designed, be made to take its full load mechanically and electrically, without falling *out of step*. Since such an alternating-current motor will not operate unless it is running at the same speed as the driving alternator, it is called a *synchronous motor*.

When synchronous motors are employed, it is, therefore, necessary to devise some means whereby they can be brought up to their normal speed before they are connected with the circuit sup-

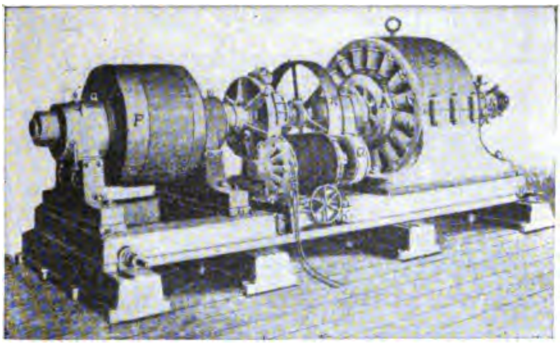


FIG. 53 —250-H.P. ALTERNATING-CURRENT SYNCHRONOUS MOTOR.

plying them. Various devices have been proposed for this purpose. The one in most general use is that shown in Fig. 53. Here the synchronous alternating-current

motor *S*, of 250 H. P., is intended to drive machinery by the pulley *P*, through the clutch *C*. In order to start the motor, the clutch is opened, and a small motor *M*, called a *diphase motor*, which will be described in a subsequent chapter, is operated, and drives the large motor armature through the friction pulleys *Q* and *R*. As soon as the armature *A*, has, in this way, been brought up to speed, the small motor *M*, is disconnected, and the armature *A*, is connected with its circuit, when it takes alternating currents, and is ready to receive its load as a synchronous motor. The clutch *C*, is then thrown in, rigidly connecting the motor shaft with the driving pulley *P*. Finally, the small driving motor *M*, is moved back by the handle *H*, so that its pulley *Q*, is out of contact with the pulley *R*. The armature *A*, receives its current through the contact

rings *G*, *G*, at the end of its shaft, and, by means of the commutator *K*, supplies the continuous currents required for the excitation of its own field magnets, in the same manner as though it were a self-excited generator.

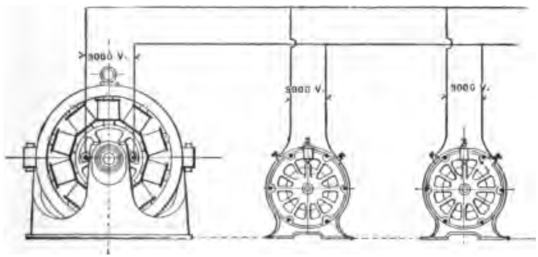


FIG 54.—ALTERNATOR WITH SYNCHRONOUS MOTORS.

Fig. 54 represents a 3000-volt alternator, suppling two synchronous motors directly from the same pair of mains, the starting motors not being shown. The pressure at the brushes of these motors is marked as being 3000 volts effective,

representing about 4200 volts at the peak of each alternation of pressure.

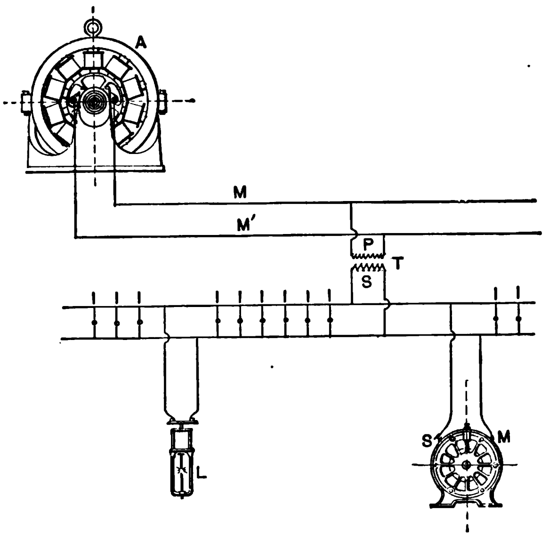


FIG. 55.—ALTERNATOR WITH TRANSFORMER AND ITS SECONDARY CIRCUIT.

Fig. 55 represents an alternator *A*, supplying a pair of high-pressure mains *M*, *M*, and a primary coil *P*, of a transformer *T*,

whose secondary coil is connected to the arc lamp L, incandescent lamps I, I, and a synchronous motor SM, all operated in parallel.

It is evident that since a synchronous motor has only one speed of rotation and requires some appreciable time to start from rest by auxiliary means, that it is unsuited to machinery which requires to be operated at varying speeds and for intermittent periods. For all purposes, however, where the power is required continuously, or for many hours a day at a steady rate, as, for example, in pumping or driving large counter shafts in a machine shop, the synchronous motor is a very useful machine.

Up to the present time no single-phase alternating-current motor, of say more

FIG. 56.—ONE-EIGHTH H.P. ALTERNATING-CURRENT FAN MOTOR.

than half a horse-power in capacity, has yet been produced in the United States, which is capable of starting at full load, from

FIG. 57.—ALTERNATING CURRENT FAN MOTOR.

rest, on ordinary alternating circuits, and which will run with a reasonable amount of economy. There are, however, a num-

ber of small alternating-current motors, some of which operate with the aid of a commutator, as, for example, the fan motor, shown in Fig. 56. Here the current through the fields is reversed at every alternation of the alternating current, but by means of the commutator, the effect of this reversal of magnetism is reversed upon the armature current, and a continuous magnetic pull produced. Unfortunately the efficiency of such machines is comparatively small, so that they are only capable of being employed in small sizes, where economy is not of much importance. Another form of alternating-current motor of this type is seen in the fan motor shown in Fig. 57.

CHAPTER VIII.

MULTIPHASED CURRENTS.

THE difficulty pointed out in the last chapter, as regards the starting of synchronous motors, has led to a special development in alternating-current apparatus called *multiphase apparatus*. The *synchronous motor* is supplied by a single alternating current. The *multiphase motor* is supplied by more than a single current. In practice either two or three currents are employed for driving multiphase motors, thus giving rise to *diphase motors*, which are supplied by two separate alternating currents, and *triphase motors*, which are supplied by three separate currents. *Multiphase motors*, therefore, require special generators for the production of the

currents they employ. We shall now proceed to discuss the construction and operation of diphase and triphase generators.

It must first be remarked that in a di-

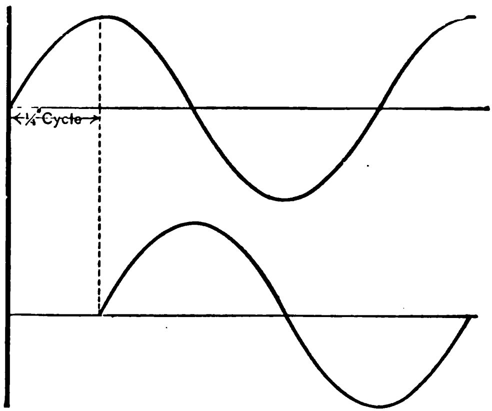


FIG. 58.—RELATION BETWEEN TWO DIPHASE ALTERNATING CURRENTS.

phase motor, for example, it is not sufficient to simply supply to the motor any two, separate, alternating currents. The

proper operation of the motor requires that the two separate currents shall possess a certain relationship to each other; namely, that one shall be a quarter of a cycle in advance of the other, as shown in Fig. 58. A *diphase generator*, therefore, must be constructed not only so as to produce two equal separate alternating currents, but these alternating currents must also have a quarter of a cycle of *phase difference* between them. Such a condition will enable the motor to start, as well as to preserve a uniform pull or *torque* upon its driving shaft.

A diphase motor is driven by two separate series of electrical impulses one quarter cycle apart. This condition finds an analogue in the ordinary steam locomotive, which, as is well known, is driven by two separate steam cylinders placed on

opposite sides of the driving engine. In the early history of the steam locomotive, when but a single cylinder was used, it was found, at times, that the engine could not be started from a state of rest, since it had stopped on a dead centre, and required, like the synchronous motor, to be started before it could by driven. This difficulty, as is well known, is now obviated by the use of two pistons, set at a quarter of a cycle, or 90° apart.

In order to obtain two separate alternating E. M. F.'s, a quarter cycle apart, in two separate circuits, either two separate windings are employed on a single armature, or two separate armatures are rigidly connected and driven on the same shaft. The latter method is represented in Fig. 59, where a 750 KW. or 1000 H. P. diphase generator is shown. This genera-

tor consists of two complete *uniphase generators A* and *B; i. e.*, generators of the ordinary single alternating-current type,

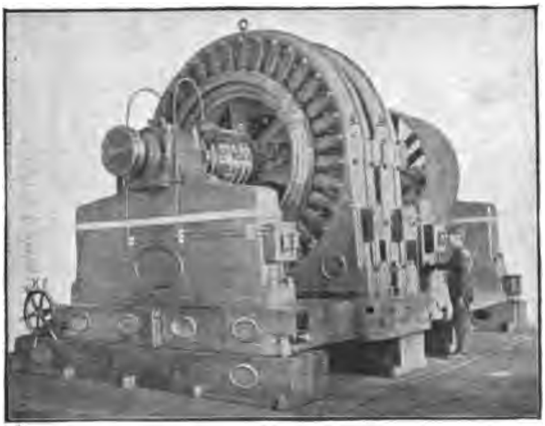


FIG. 59.—750-KILOWATT COLUMBIAN EXPOSITION, DIPHASE ALTERNATOR.

rigidly connected together in such a manner that the armature of one machine is just far enough ahead to produce its alter-

nating E. M. F. a quarter of a cycle in advance of that of the other. This machine is compound-wound, supplying its field magnets partly from the commutator *C*, and has three collector rings *R*, *R*, *R*, one of the outside rings for each current and the middle ring, as a common con-

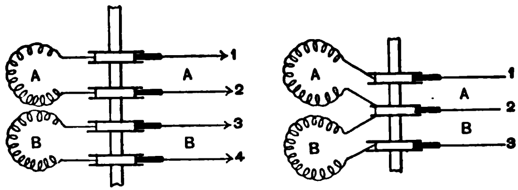


FIG. 60 —DIAGRAM SHOWING THE TWO METHODS OF CONNECTING DIPHASE ARMATURE WINDINGS THROUGH COLLECTIVE RINGS WITH EXTERNAL CIRCUITS.

nection for both, as shown in Fig. 60. The belt tightening handle is shown at *H*.

Another form of diphase generator is shown in Fig. 61. Here a single armature has two windings, the E. M. F. in one of which is developed a quarter of a cycle

before the other. The three conductors *A*, *B*, *C*, carry off the two diphase currents, while the conductors *F*, *F*, supply

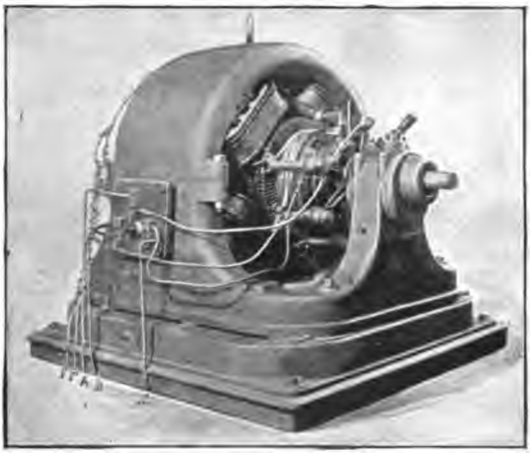


FIG. 61.—100-KILOWATT MULTIPHASE GENERATOR

the field with a continuous current. The commutator *C*, supplies current to the field magnets.

Another form of diphase generator is

represented in Fig. 62. Here two separate external armatures *A* and *B*, do not revolve, while within them revolves the field magnet driven by a pulley *P*. The

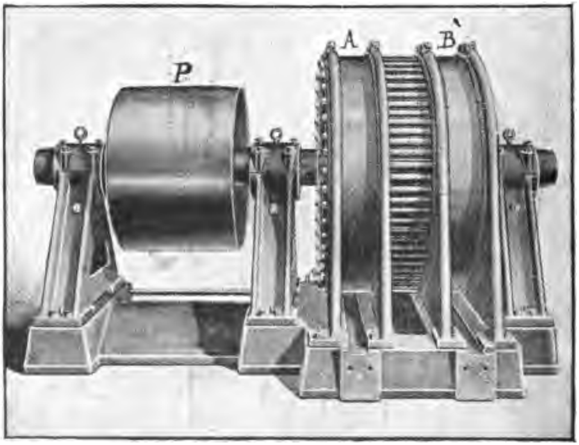


FIG. 62.—DIPHASE ALTERNATING-CURRENT GENERATOR.

E. M. F. in one armature, say *A*, is developed a quarter of a cycle, or half an alternation, ahead of that in *B*.

The circuits of such a diphase generator require, as shown in Fig. 60, either three or four wires. If four wires are employed, the two separate circuits are entirely distinct, while if three wires are employed, one of the conductors is common to both circuits.

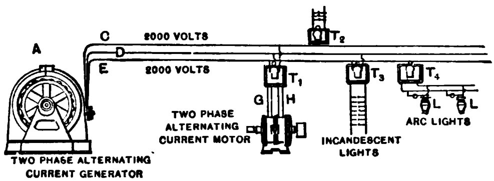


FIG. 63.—DIPHASER AND ITS CIRCUIT.

In Fig. 63, a diphase generator or *diphaser* is represented at *A*. The two separate currents, generated in this machine, are led to the transformers T_1, T_2, T_3, T_4, through the three wires of the circuit. The pressure at the generator brushes is 2000 volts effective, beween *C* and *D*, or between *D* and *E*. The transformers T_2,

T_3 and T_4 are connected between a single pair of wires; namely, T_2, between C and D, T_3 between D and E, and T_4 between D and E, so that only one current is supplied to each of these transformers. In all cases, where diphase currents are not to be used simultaneously in a motor, they are separately used as uniphase currents either in lamps or in synchronous motors. T_4 is a transformer on one of the circuits supplying arc lamps L,L, at a pressure of, perhaps, 50 volts. The transformer T_1, which is really a double transformer, half between the wires C and D, and half between the wires D and E, supplies in its secondary circuits G and H, diphase currents to the diphase motor M.

A *triphase generator* or *triphaser* is a generator which produces three separate alternating E. M. F.'s separated from each

other by one third of a cycle, as represented in Fig. 64. Such a machine is shown in Fig. 65. Here the armature has three separate windings upon it, so arranged that the E. M. F.'s generated in

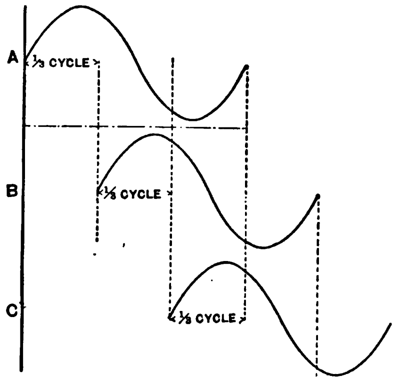


FIG. 64.—DIAGRAM REPRESENTING PHASE RELATION OF TRIPHASE WAVES OF E. M. F. AND CURRENT.

them succeed each other by one third of a cycle. Three collector rings R^1, R^2, R^3, on the right hand armature on the shaft, carry off the current as shown in Fig. 66, to three wires, AA^1, BB^1, CC^1, each of

which serves as a return circuit for the other two.

The motor windings, transformers, or other devices are connected between the

FIG. 65.—500-KILOWATT TRIPHASE GENERATOR.

wires as at $A^1 B^1$, $B^1 C^1$, or $C^1 A^1$. Triphasers possess electrical features which have gained for them considerable favor. A triphaser only requires three wires for its

three currents. A diphaser requires four wires but can be operated with three.

Beside the diphase and triphase generators another system has come into recent

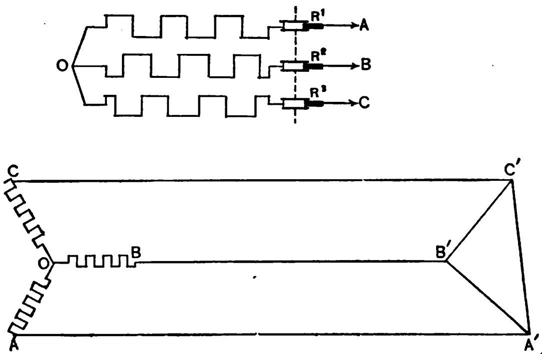


FIG. 66.—DIAGRAMS REPRESENTING CONNECTIONS OF TRIPHASE WINDINGS WITH THEIR EXTERNAL CIRCUITS.

favor, called the *monocyclic system.* The *monocyclic generator*, or *monocycler*, is primarily a uniphase generator, and is intended principally for the delivery of ordinary alternating or uniphase currents,

over a system of electric lighting mains. In order, however, to supply starting alternating-current motors wherever they may be installed in the system, a special series of coils, of smaller size and cross-section, is placed on the armature so as to produce a small E. M. F. a quarter cycle out of step with the main uniphase E. M. F. This smaller E. M. F. is connected to a third collector ring on a special circuit wire, called the *power wire*, which has a smaller cross-section than the main uniphase wires, and is led only to where the motors are to be used. By the use of two transformers, connected with the power wire and the main wires, triphase E. M. F.'s are produced in a secondary circuit for the operation of triphase motors, while between the main wires in all other parts of the system, ordinary uniphase E. M. F.'s are maintained.

A form of belt-driven 150 KW. monocyclic generator is represented in Fig. 67. Here the three collector rings are shown

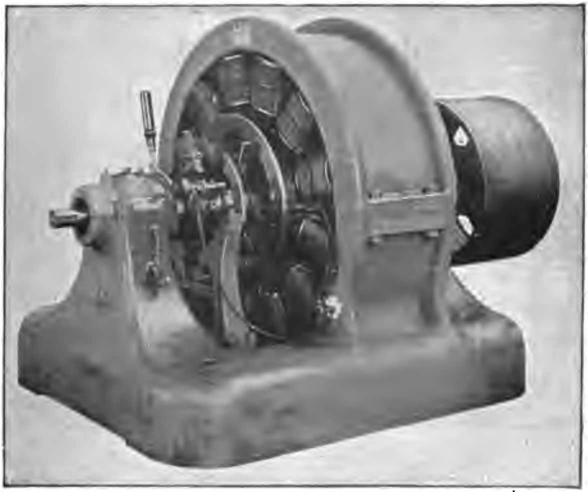


FIG. 67.—150-KILOWATT MONOCYCLIC GENERATOR.

at *R*, *R*, *R*, and the commutator *C*, is for the compounding of the field magnets. Fig. 68 represents the armature of such a

machine, with its three collector rings and its commutator. It is often found difficult to determine, from the appearance of such a machine, whether it is of the monocyc-

FIG. 68.—MONOCYCLIC ARMATURE.

lic, diphase, or triphase type, but a close inspection of the armature will usually indicate that the main coils *ZZ*, *AA*, *BB*, are larger than the intermediate coils or lesser coils *T*, *T*, *T*, *T*, *T*, *T*.

CHAPTER IX.

MULTIPHASE MOTORS.

PRIOR to the introduction of the multiphase machinery there were but two methods whereby electric power could be commercially transmitted over a considerable distance; namely, either by the use of continuous-current motors, or by the use of synchronous alternating-current motors. As we have already pointed out, in order to obtain the advantages of the electrical transmission of power it is necessary to employ a high pressure on the conducting line so as to save copper in the conductor. While this is possible by the use of continuous-current motors, and, in point of fact, has been employed, yet the presence of commutators, which

such a system necessitates, both on the generator and motor, has been found, in practice, to give rise to no little risk and trouble, since the total pressure between the lines, being thus brought directly to the opposite sides of the commutator, should an arc discharge occur over the commutator, there would be a danger of its destruction.

In order to lessen these difficulties, the plan has been tried of distributing the line pressure to a number of motors all rigidly connected to the same shaft, and traversed successively by the driving current. If, under a line pressure of say 2500 volts, five motors were so coupled together, then each motor would receive a pressure of one fifth of the total, or 500 volts. Although this device reduces the pressure across each commutator, yet the insulation of each machine has to be carefully main-

tained, since, otherwise, a discharge might take place through the commutators to the shaft, under the whole pressure of the line, thus disabling the plant. Consequently, early in the history of alternating currents, appreciating the advantage in practice, arising from the absence of a commutator, the uniphase generator and motor were connected, by means of conducting lines, for power transmission. To a certain extent this combination was successful; for, as has already been pointed out, beside the advantage of collecting rings instead of commutators, the system possessed a marked advantage from the ease with which the pressure could be varied by the aid of suitable transformers. When the line pressure is too high to employ safely at the brushes of generator and motor, these latter can be constructed for lower pressures and larger currents, and then,

by the use of step-up transformers at the generator, and step-down transformers at the motor, all the advantages of high pressure in the line, and low pressure at the machinery, can be secured, without great additional risk or cost. Such a system of transmission, however, necessitates the employment of the uniphase synchronous motor, and was, therefore, totally unfitted to cases where the motor had to be frequently stopped and started.

Happily these practical difficulties in the commercial transmission of power have been removed by the introduction of multiphase alternating-current apparatus, and while it is true that the use of such apparatus necessitates the employment of at least one additional conductor, yet the advantages possessed by the multiphase system are so considerable, that even al-

though this conductor involved extra cost in the copper, yet the advantages obtained would render its adoption economical. In point of fact, however, the amount of copper actually required for the three-wire multiphase system is one fourth less than that for the same amount of power by the uniphase system employing the same pressure in the line.

As at present employed multiphase currents are readily divisible into diphase, triphase, and monocyclic. Consequently, it will be convenient to treat motors under the same general heads. In point of fact, however, the difference between these forms of motors is comparatively trivial. A diphase motor differs from a triphase motor mainly in the fact that it has two circuits in its fields instead of three.

In order to understand the operation of any multiphase motor, we will consider the effect produced on a suitable field-winding when multiphase currents are supplied to it. It is necessary to remember that two separate alternating currents, flowing through two separate circuits, do not form a diphase system, unless the two currents differ in phase by a quarter cycle, or are 90° apart. When such diphase currents are sent through properly wound field frames, they tend to produce in them a magnetic field of a curious character; namely, the poles produced do not only alternate in direction with changes in the direction of the current, but act as though the field rotated. For example, if in Fig 69, we consider the pair of coils 1, 3, on the opposite sides of the field frame, and suppose that a single uniphase current is supplied to them, it is evident, that if dur-

ing any wave of current the pole 1 is a north pole and 3, a south pole, then during the next wave of reversed current, these poles will be reversed or 1 will be

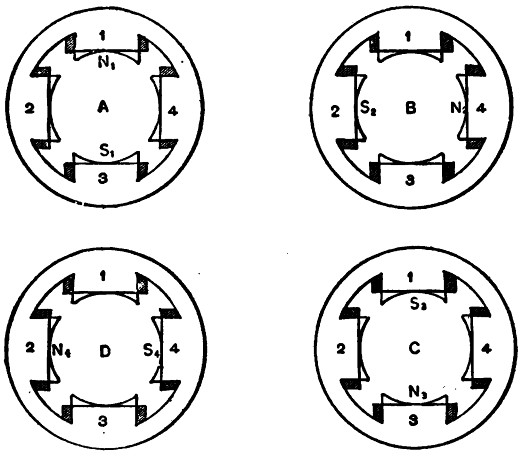


FIG. 69.—DIAGRAMS ILLUSTRATING EFFECTIVE ROTATION OF A DIPHASE MAGNETIC FIELD.

south, and 3, north. The same conditions will be maintained in the adjacent poles 2 and 4, which are alternately north and south, and south and north. But if the

waves of current through C and D, come half an alternation later than the waves in A and B, we obtain a series of conditions represented; namely,

(A) 1 is north, 3 is south, while 4 and 2 are in transition, there being no current in them at that instant.

(B) In the next quarter cycle, 4 and 2 are now active, while 3 and 1 are in transition.

(C) At the next quarter cycle 3 and 1 have again come into action in the opposite direction, while 2 and 4 are in transition, and finally:

(D) In the fourth quarter of the cycle, 1 and 3 are in transition, while 4 and 2 are active. If, now, we examine these figures we shall see that the N. and S. poles have steadily progressed around the field frame in the direction of the hands of a clock, so that, although alternating currents have

been employed, yet by reason of their proper phase difference in the two separate circuits, their effect has been to cause the magnetic field to rotate. If a compass needle were introduced into the middle of the field frame, it would, if left free to spin around the axis, rotate about that axis at the rotary speed of the field; namely, one revolution per cycle. Such a rotating compass needle may be considered as a small armature capable of acting as a motor. A piece of soft iron pivoted upon an axis at the centre will revolve in the same way. In practice it is usual to construct a laminated armature core, like that of a continuous-current motor, wound with closed coils or closed loops, so as to induce powerful currents in these coils by the rotation of the magnetic flux through them, and thus develop a powerful magnetic attraction between the revolving magnetic field

and these currents. Such motors are therefore sometimes called *induction motors*.

In order to reverse the direction of a polyphase motor it is only necessary to reverse the direction of one of the windings on the motor, so as to reverse one of the pairs of poles, when the field will rotate in the opposite direction. With the apparatus actually employed a switch is arranged, so that, by its motion, one of the field windings is reversed.

A triphase motor differs from a diphase motor only in that its field windings contain either six coils, or some multiple of three, instead of four coils or some multiple of four. The effect of the current waves succeeding each other in the different windings, by one third of a cycle, produces a continuously rotating field.

Fig. 70 represents a 15 H. P. diphase motor. *FF* is the field frame of laminated iron with suitable windings inside to pro-

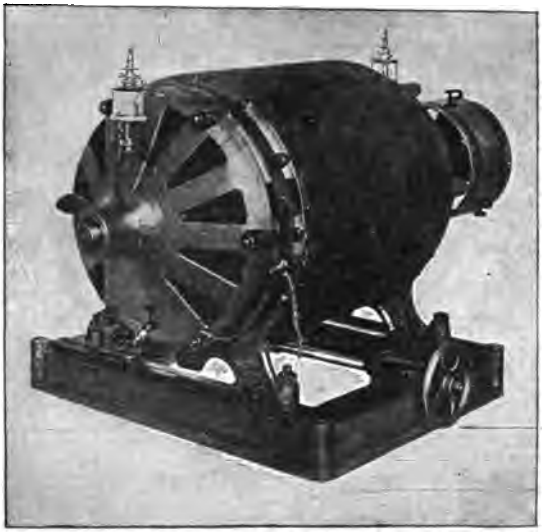


FIG. 70.—FIFTEEN HORSE-POWER DIPHASE MOTOR.

duce the revolving field, within which the armature rotates driving the pulley *P*.

It is important to observe that in synchronous motors, the field frame need not be laminated, since the field poles do not change polarity, being excited by a continuous current, but in multiphase motors, since the field magnets are excited by alternating currents, it is important that the iron be laminated, in the frame as well as in the armature, since, otherwise, loss of power and injurious heating would occur.

Fig. 71 shows a form of triphase motor for 7 1-2 horse-power. The three conducting wires are led through the winding of the field to the terminals *A*, *B*, *C*, and the armature shaft has a series of contacts *C*, which is not a commutator, although somewhat resembling one in appearance. When the handle *H*, is in the position shown, certain resistances

are included in the circuit of the armature windings, so as to enable the motor to start from rest. It is found, that if the full pressure be supplied to the field of

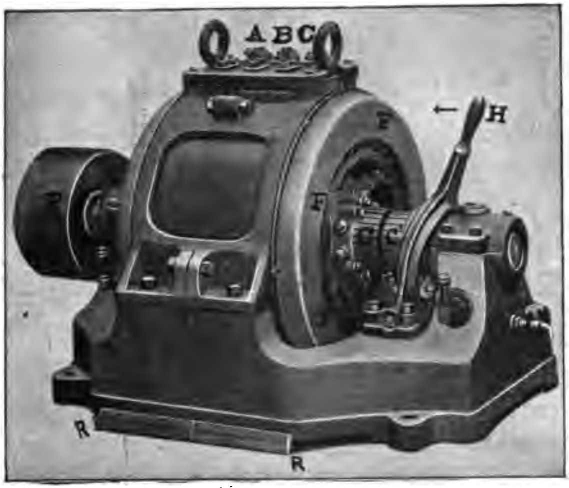


FIG. 71.—TRIPHASE INDUCTION MOTOR, 7½ H.P.

the motor with the armature in its ordinary short-circuited condition, such powerful currents are induced in the armature

as to weaken its starting power. By the insertion of extra resistance, however, these currents can be reduced to the proper strength in the armature circuits to obtain a powerful starting power or *torque*, and, when the machine has attained full speed, the handle is pushed in toward the field frame, thereby sliding the contact ring *C*, into the strong clips of C^1, short-circuiting the extra resistance, and cutting it out of circuit. The size of this motor is indicated by a foot-rule *RR*, shown at its base.

Fig. 72 represents a similar triphase motor for 125 H. P. The three terminals of the field winding are shown at the top of the frame *F*, *F*, *F*, *F;* within revolves the armature A, A, A. As in the last case, the handle *H*, when the motor has been brought up to speed, throws forward a

collar *K*, into a receptacle, thus cutting the *starting resistance* out of the circuit of

FIG. 72.—125-HORSE-POWER INDUCTION MOTOR.

the armature coils. It will be seen that these triphase motors are very simple in appearance, have self-oiling bearings, and,

having no commutator, require the minimum of attention.

Another form of small induction motor is represented in Fig. 73. This is a tri-

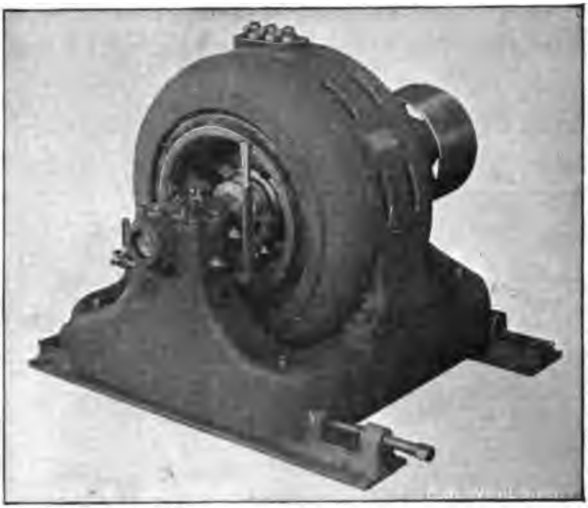


FIG. 73.—MONOCYCLIC MOTOR.

phase motor frequently operated on a monocyclic circuit.

Figs. 74 and 75 show a form of diphase motor, with front and rear view. The three collector rings R^1, R^2, R^3, are em-

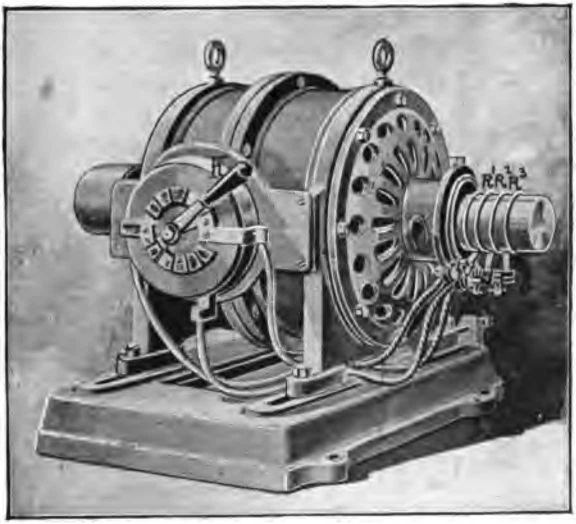


FIG. 74.—DIPHASE MOTOR.

ployed for the purpose of inserting resistance in the armature circuits under the control of the handle *H*, which is only

employed in starting the motor. As soon as full speed is reached, the additional resistance is entirely cut out of circuit.

The interior of the field frame for this

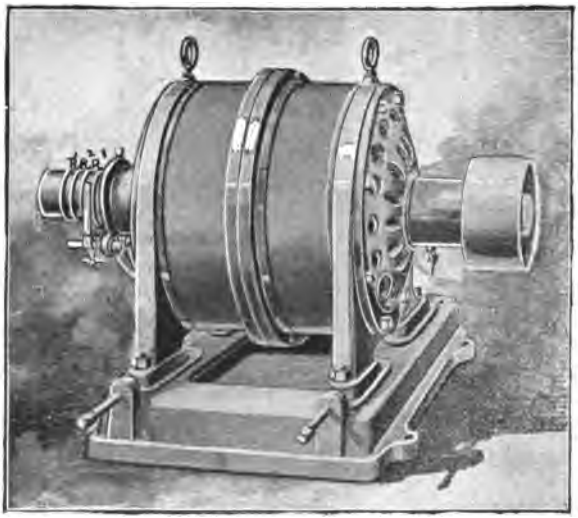


FIG. 75—DIPHASE MOTOR.

motor is represented in Fig. 76. It will be seen that there are two separate field frames placed side by side, but differing

in relative position. One of the two diphase currents supplies the series A, B, C, and the other diphase current, the series A^1, B^1, C^1. Under these conditions, al-

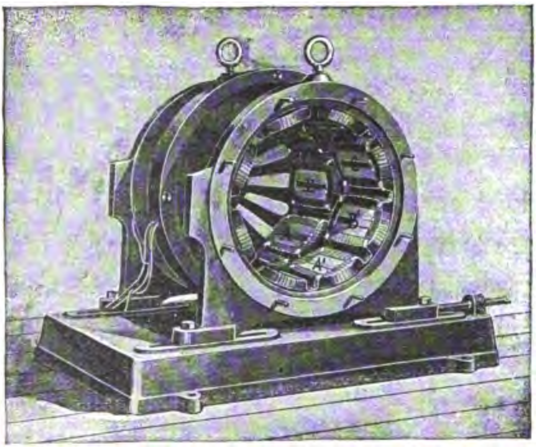


FIG. 76.—MOTOR FIELD.

though no rotating magnetic field is produced, yet by the effect of these alternating magnetic poles upon the armature, a rotating magnetic field is developed upon

it. The armature is represented in Fig. 77. At *A*, the core is shown, consisting of two separate halves H^1 and H^2, each revolving under one series of field magnets in the field frame. The appearance

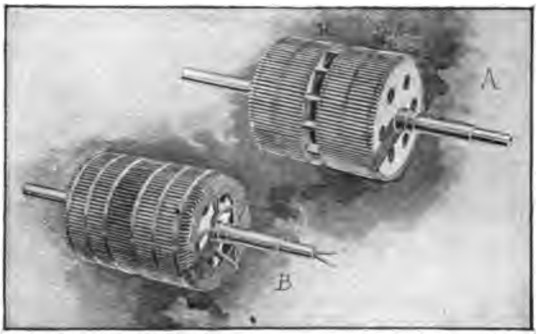


FIG. 77.—MOTOR ARMATURES.

of the armature after winding is shown at *B*, where the wire occupies the grooves between the iron teeth on the armature surface. The winding is carried completely across the double armature, so

that the currents produced in the winding by one series of field poles react upon the neighboring series. This motor is designed for a frequency of about 130 cycles per second. Triphase and diphase motors, while they can be designed for other frequencies, are more commonly employed at a frequency of 60 or 30 cycles per second.

The practical trend at the present time is toward the introduction of multiphase systems for the transmission of electric power. This tendency has resulted from the great flexibility possessed by multiphase systems.

Such, in brief, is a description of the more important commercial applications of alternating-current apparatus. When we consider that the developments in this latest field of electrical improve-

ment have occurred practically within less than a decade, we cannot but believe that the next decade will witness even still greater improvements in this rapidly-advancing art.

CHAPTER X.

RECENT PROGRESS IN ALTERNATORS.

Modern alternators, in large sizes, are usually multiphase, and are commonly constructed with stationary armatures. They are multiphase, because a considerable portion of the load is usually motive power, and large alternating-current motors require to be supplied with multiphase currents. Moreover, long-distance transmission is most economical in weight of conductor, for a given voltage, by the three-phase system. The stationary armature, with a revolving internal field, not only permits of great simplicity of structure in the revolving element or rotor, but also en-

ables a better insulation to be obtained on the stationary armature coils, whereby a higher generator pressure, or terminal voltage, can be safely obtained than if the armature were the rotating element. The high-pressure connections are also fixed and can be well insulated, instead of being made through the medium of moving slip rings and exposed brushes. On this account the alternating-current pressure delivered by large generators is sometimes as high as 15 kilovolts, thereby frequently dispensing with the necessity for step-up transformers at the generating station. A 1,000 KW. triphase direct-connected generator, with revolving field, is represented in Fig. 78. In some cases the revolving field is replaced by a fixed field coil, and a rotating set of field cores, or inductor. A diphase inductor-generator is illustrated in Fig. 62.

Large alternators are usually uncompounded and require, therefore, to have their excitation regulated by hand, in order to maintain constant potential under varying load. The automatic regulation of pressure, on non-inductive load, is frequently 7 per cent., so that a machine which would deliver say 1,000 volts at no load, in each of its multiphase circuits, would deliver 930 volts at full non-inductive load, if the speed of the generator remained constant. A non-inductive load is one in which the power factor is 100 per cent., or in which the current is exactly in phase with the generated pressure in each circuit. On the other hand, an inductive load is one in which the power factor is appreciably less than 100 per cent., and in which the current in each multiphase circuit either leads or lags behind the E. M. F. in that circuit, the usual condition being

FIG. 78.—1,000 KW. TRIPHASE REVOLVING-FIELD GENERATOR.

that of lag, due to the presence of a considerable magnetizing, or wattless

component of current, as distinguished from a working, or active component of current. An inductive load is described by its power-factor; thus an inductive load of 80 per cent. power-factor, represents a load in which the real power, or watts, is 80 per cent. of the apparent power in volt-amperes, or product of terminal volts and amperes. A circuit, or set of multiphase circuits, tends to become inductive by reason of the presence of choking coils or magnetizing coils. Thus, a considerable number of induction motors, especially if operated at light load, will be accompanied by a small power-factor and large magnetizing or wattless component of current.

If $O\ P$, Fig. 79, be a straight line drawn to scale, to represent the volt-amperes, or apparent power, delivered by a genera-

tor, either per circuit, or in all its circuits, and if *op* represents, to the same scale, the real power in watts delivered at generator terminals, then, if we divide the length *op* by the length *O P*, we obtain as

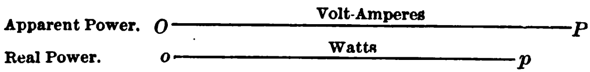


FIG. 79.—DIAGRAM OF REAL AND APPARENT POWER.

the quotient, the power-factor of the circuit or circuits at the generator terminals. In the case selected this ratio is $\frac{86.6}{100}$ or 86 per cent. Moreover, if, as in Fig. 80, the line *o p*, be laid off from the origin of *O P*, at such an angle that the angle *O p P*, is a right angle, the angle *p O P*, between the two lines is called the *phase angle* between the current and E. M. F. in each circuit. The current is represented as lagging behind the pressure by reason

of the action of inductance in the magnetizing coils. The same diagram represents at a glance the relative proportions of working and magnetizing currents, because if OP be regarded as representing the

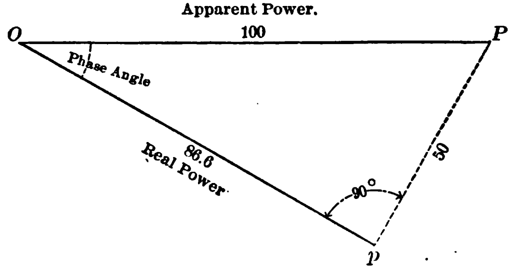


Fig. 80.—Relation of Angle of Lag to Power Factor.

current per circuit at machine terminals, then Op will represent the working current, or the component of current in phase with, or in step with, the E. M. F. in that circuit; while the component pP will represent the magnetizing, or wattless component, which alternates in the circuit

without carrying electric power. The presence of this wattless component is objectionable, not only because it heats the armature of the generator, but because, by reason of its phase displacement, it produces a relatively large drop of pressure in the generator armature. Consequently, an alternator, which might automatically maintain the pressure at its terminals under full non-inductive load within 7 per cent., or which might have an inherent regulation of 7 per cent., on non-inductive load, might readily increase its drop of pressure at terminals, under inductive load, to 15 per cent. or more, so that the excitation of the machine would not only require to be more closely watched with variations of inductive load than with variations of non-inductive load, but the excitation would have to be varied much more widely to meet changes of inductive

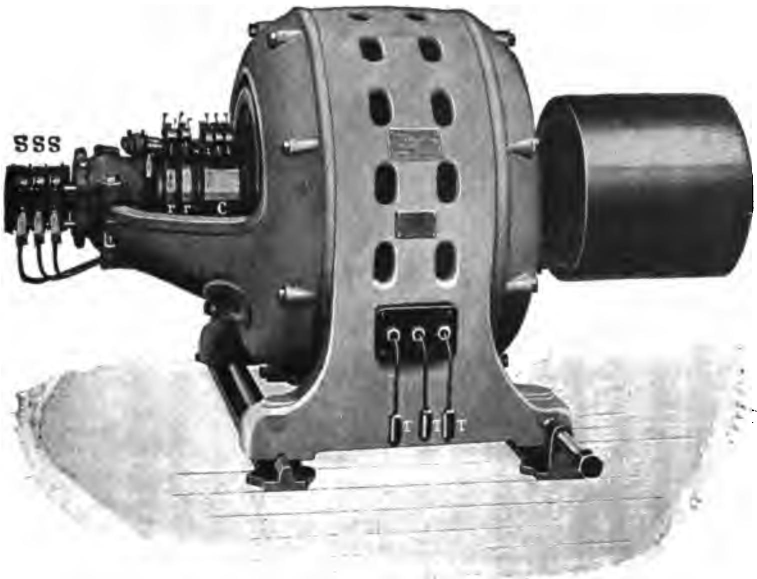


FIG. 81.—COMPENSATED REVOLVING-FIELD TRIPHASE ALTERNATOR.

load, than to meet corresponding changes of non-inductive load. It is evident, therefore, that any adequate automatic compounding of an alternator must necessarily compensate not only for variations in the magnitude of the delivered current, but also for variations in the phase angle of the current, or the power-factor of the load.

Of recent years improvements have been made in the direction of compounding alternators, both for the magnitude and for the phase of the current delivered, so that the excitation shall be increased in the desired proportion when the power factor of the load diminishes. Fig. 81, shows a General Electric Company's 75 KW, octopolar, belt-driven, compensated, revolving-field, triphase alternator. This machine consists of alternator and exciter

associated in a single structure. The alternator triphase armature is mounted in a stationary frame, and its fixed terminals are shown at *T, T, T.* It is the object of the compounding, or compensation, to maintain the pressure at these terminals as nearly constant as possible, under all variations of current and power-factor within the range of the machine. On the revolving shaft are mounted, side by side, the multipolar field of the alternator and a multipolar winding of the direct-current type, having the same number of poles, and corresponding to the armature of the exciter. This exciter winding is connected to the commutator *C,* and the carbon brushes resting on this commutator supply a rectified or direct current from the commutator and exciter armature to the revolving field of the alternator through the slip rings *r, r.* The exciter winding is

tapped at three magnetically equidistant points (corresponding to points 120 circular degrees apart in a bipolar armature), which points are connected to the three slip rings *s*, *s*, *s*. Fixed brushes, resting on these rings, supply through them, to the revolving exciter armature, low-pressure alternating currents obtained from series transformers in the main circuits of the alternator.

Under the above conditions the exciter armature is virtually supplied with a definite portion of the alternator armature line currents. The exciter armature-winding is subjected to the action of two magnetizing forces. One of these is produced by the stationary field-poles surrounding the exciter armature, and receiving direct current from the brushes on the commutator *C*. The other is a stationary set of field-

poles produced by the multiphase alternating currents, virtually tapped from the main line, and supplied to the revolving exciter winding by the rings *s*, *s*, *s*. If there be no current supplied to the lines from the alternator armature, the exciter winding will be operated like an ordinary series-wound, direct-current generator, and will supply direct-current excitation to its own stationary field magnets, as well as to the revolving alternator field magnets. If the alternator supplies say full-load current at non-inductive load, the line currents, transformed to low-tension, and supplied through the slip rings *s*, *s*, *s*, produce in the revolving exciter armature a new multipolar magnetomotive force stationary in space, but so located with respect to the stationary exciter field-poles and to the brushes on the commutator *C*, that the E. M. F. generated in the exciter armature,

and the current supplied from its commutator are only increased about 12 per cent. This will raise the alternator E. M. F. say 10 per cent. and restore the pressure at the generator terminals *T*, *T*, *T*. If, however, the load becomes inductive, as, for example, by the presence of induction motors, and the lagging currents supplied to them, the alternator armature currents will lag, and the position of the multipolar magnetomotive force, established thereby in the exciter, will be displaced in such a manner as to coincide more nearly with the stationary exciter field-poles, and, therefore, to assist them, the two magnetizing components being thus brought more nearly into line. Under these conditions the same strength of current in the line will cause the direct-current taken from the commutator *C*, to be increased, perhaps, 25 per cent., and the alternator field will be

strengthened in corresponding degree. This will compensate for the greater drop in the alternator armature due to lagging currents, and will restore the required constant potential at the main terminals *T*, *T*, *T*.

CHAPTER XI.

SOME RECENT DEVELOPMENTS IN TRANSFORMERS.

In all large sizes of transformers a difficulty exists in keeping the apparatus cool. The full-load waste of energy in a transformer increases nearly in proportion to its weight, whereas the surface of the apparatus, through which that waste energy must escape as heat, increases less rapidly, and only as the two-third power of that weight for the same general type of construction. Consequently, the temperature elevation of the apparatus tends to increase with its size and weight.

Transformers may be divided into

classes, according to the method employed for cooling them. These are:

(1) Air-cooled transformers, both by natural draught and by artificial or forced draught.

(2) Oil-cooled transformers, both by natural circulation of oil, and by forced water circulation through pipes immersed in oil.

A form of General Electric Company's natural-draught air-cooled transformer is shown in Fig. 82, with its cover removed. Here the iron core is formed of two uprights of laminated sheet iron, connected above and below by horizontal bars, or yokes, of sheet iron, thus forming a hollow rectangular frame of iron. Around the two uprights are placed the windings, the secondary coils being on the inside nearest to the cores, and the primary windings on

FIG. 82.—NATURAL-DRAFT AIR-COOLED TRANSFORMER.

the outside of these; *R*, *R*, are tie rods clamping the iron-core structure; *S*, *S*, are

FIG. 82A.—NATURAL-DRAFT AIR COOLED TRANSFORMER.

the secondary terminals. These transformers are made in sizes from 5 to

200 KW. and in pressures up to 10 kilovolts. The cover of the apparatus of corrugated sheet iron is shown in Fig. 82A. Air spaces are seen to be left both above and below, to facilitate the natural ventilation of the apparatus.

In larger sizes of air-cooled transformer, an air blast, or forced ventilation, has to be resorted to for cooling. Fig. 83, shows a General Electric Company's air-blast transformer of 200 KW. capacity, with the high-pressure electric connections at the top of the case. The base of the apparatus is hollow, and connected with an air supply pipe, through which air is forced by an auxiliary motor and blower, the auxiliary power thus required being usually a small fraction of one per cent. of the transformer output. The interior parts of the transformer, in course of con-

FIG. 83.—AIR-BLAST TRANSFORMER.

FIG. 84.—AIR-BLAST TRANSFORMER IN PROCESS OF CONSTRUCTION.

struction, are shown in Fig. 84. Here the coils form a vertical hollow rectangular frame, around the upright legs of which

are assembled thin flat sheets of steel forming the core. Spaces are left at intervals between the sections of the core to permit of the circulation of air. The air passes from the base, or wind chest, vertically through the transformer coils, and also horizontally, from one side of the apparatus to the other, through the core. The rate of admission of air is controlled by shutters or dampers in the top and side of the apparatus. In some forms the low-pressure terminals are brought out through the base, and in other forms through the top, on the opposite side to the high-pressure terminals. These transformers are constructed in sizes from 50 KW. to over 1,000 KW.; and their output varies from 25 to 50 watts per pound of weight. The output-per-pound increases with the size, and also to some extent with the frequency of alternation. Standard frequencies are

60 cycles and 25 cycles per second, and the weights are about 20 per cent. less for the higher frequency.

Small sizes of oil-cooled transformers depend upon the natural convective circulation of the oil for the dissipation of the heat. The transformer is completely immersed in the oil, and the heat, generated during operation in its core and coils, is communicated to the oil, which in turn communicates the heat to the iron tank or enclosing shell. The external surface of the tank is sometimes deeply corrugated to aid air convection in carrying away the heat. In large sizes of oil-cooled transformers, a water jacket or circulation of water in a spiral pipe has to be used, since the uppermost layers of oil tend to become the hottest, and the heat is apt to accumulate to an extent which involves an unde-

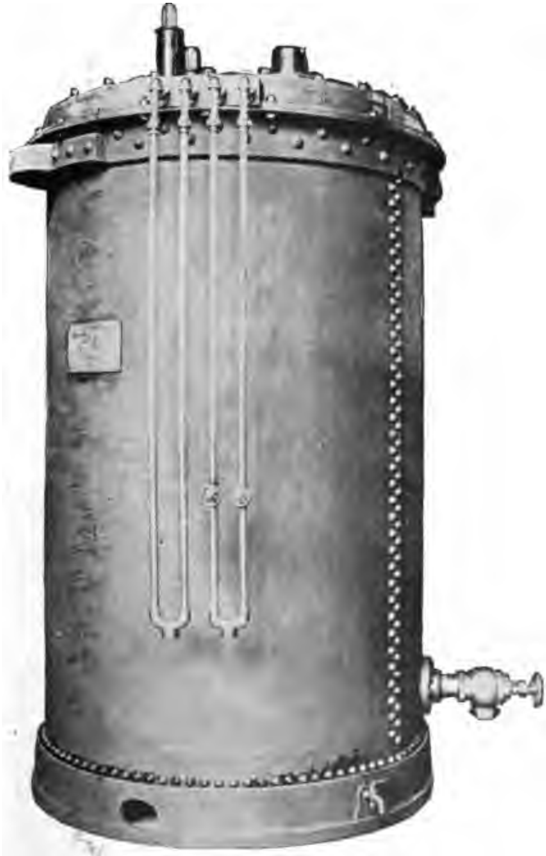


Fig. 85.—950 KW. Water-Cooled Transformer Case.

sirable temperature elevation unless forced circulation is resorted to.

The oil used in such transformers has the property of not only acting as a cooling circulating medium, but also of assisting in maintaining the insulation of the apparatus. Oil is, moreover, a substance which has a great dielectric strength, or resistance to disruptive discharge, and if a momentary spark discharge should take place through it, the oil possesses the power of automatically sealing up the puncture, a property which is not possessed by solid dielectrics.

In large sizes of oil-cooled transformers the heat is carried from the oil by the coil of stout iron pipe without joints, through which cold water is allowed to circulate slowly. The interior and exterior of a

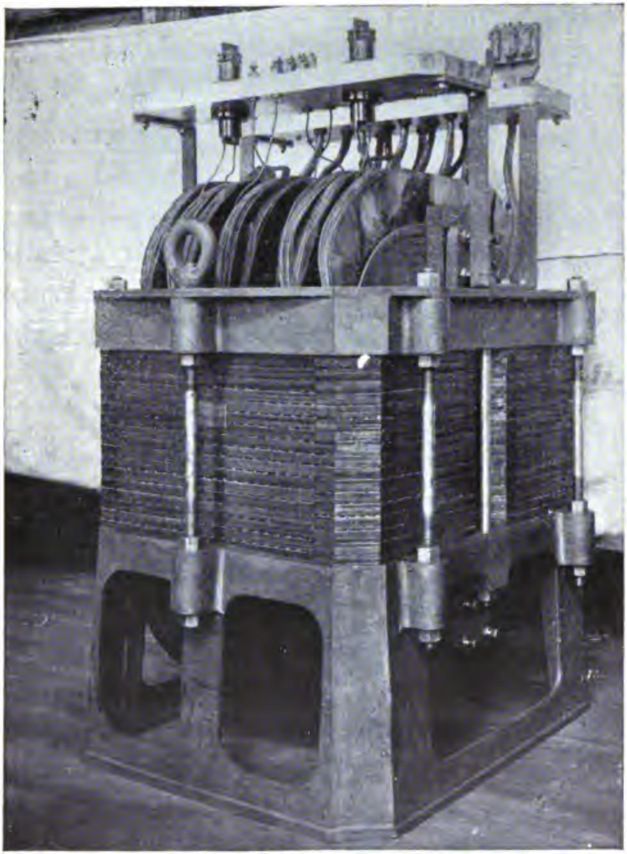


FIG. 86.—950 KW. WATER-COOLED TRANSFORMER.

Westinghouse water-cooled transformer is shown in Figs. 85 and 86, while a similar type of General Electric transformer is shown in Figs. 87 and 88, respectively. Transformers are now in use in sizes up to 1,875 KW. The efficiency of these large transformers is 98.5 per cent. at full load, and 97.6 per cent. at quarter-load, with a 1 per cent. regulation at full non-inductive load.

Considerable improvements have been made, of recent years, in the efficiency of transformers. The loss of energy which occurs in magnetizing or exciting a transformer is almost entirely expended in the iron core, only a very small magnetizing current and loss in the primary coil occurring under such circumstances. This core loss is mainly due to *hysteresis* (hiss-ter-eé-siss) in the iron; *i. e.*, the

FIG. 87.—WATER-COOLED OIL TRANSFORMER, WITHOUT CASE.

property which iron has of magnetically lagging behind the magnetizing current, or of resisting magnetization. The crests of the alternating magnetization-waves in the iron consequently lag behind the waves of the magnetizing alternating current. Every time that a mass of iron has its magnetization reversed, a certain amount of energy is expended in it as heat, the amount depending upon the mass of iron, and also upon the extent to which the magnetization is carried. For a given density of magnetization, the amount of energy expended in hysteresis depends simply upon the number of reversals or cycles of magnetization, and upon the number of pounds of iron subjected to such reversals. It also depends upon the magnetic quality of the iron. In other words, each pound of iron cyclically magnetized to a given magnetic density, absorbs and wastes

as heat, a definite small amount of energy in each cycle. As a general rule, the softer the iron the less the hysteretic loss in its cyclic magnetization. Moreover, the hysteretic loss in transformer cores usually tends to increase slightly during the first few weeks or months of service, when they attain a permanent hysteretic condition. Much experimental study has of recent years been devoted to the choice of steel used in transformers, and as a result the initial hysteretic loss per pound and per cycle has been considerably reduced, while the further increase in hysteretic loss with age has been still more reduced. The *core loss*, or *iron loss*, of a transformer, is particularly objectionable, because it occurs continuously in steady operation, and is practically independent of the load; whereas, the *copper loss*, or that occurring in the coils of wire by virtue of their resist-

Fig. 88.—Water-Cooled Oil Transformer, with Case.

ance, is almost entirely absent at no load. In sizes of transformers above 5 KW. capacity, the core loss is usually in the neighborhood of 1 per cent. of the output, and this percentage diminishes with the size of transformer, being about 1/2 per cent. in the largest transformers.

Owing to the fact that the core or iron loss of a constant-potential transformer is pratically independent of the load, while the copper loss, due to the resistance of the winding under load, increases, approximately, as the square of the load, it can be shown that the maximum efficiency of any constant-potential transformer is very nearly attained at the load for which the copper loss and iron loss are equal in amount.

Although the efficiency of a transformer

is almost always between 90 per cent. and 98.5 per cent. at full load, according to its size, yet if there are long periods of time during which the transformer is excited from the mains but yet remains on no load, or on open secondary circuit, the *all-day efficiency*, or average efficiency, may be considerably less than 90 per cent., and modern improvements in the manufacture of transformers, by reducing the core losses, have tended considerably to increase this *average efficiency*, or the ratio of output to input, for a year's continuous operation.

CHAPTER XII.

PHASE TRANSFORMATION.

IT is sometimes desirable to change from a two-phase to a three-phase system, or vice versa. For example, when two-phase generators supply long-distance transmission lines, there is an economy in conductors, for a given maximum voltage between lines, in substituting three-phase transmission for two-phase transmission. The method which is ordinarily employed for accomplishing this result, depends upon the fact, that when a number of electromotive forces, differing in phase, are connected together at some connecting or junction point, the resulting electromotive

force between the various points of the electric system so formed can be ascertained by a simple geometrical construc-

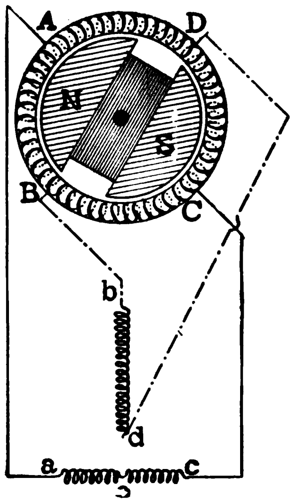
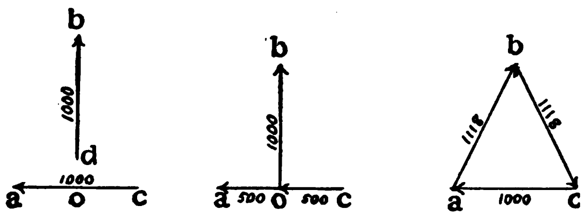


FIG. 89.—DIAGRAM OF DIPHASE GENERATOR.

tion. Thus, the diphase generator of Fig. 89, having a stationary armature *A B C D*, and a rotating internal field

magnet *N S*, supplies two choking coils *a c* and *b d*, with terminal electromotive forces, each of 1,000 volts, and in diphase, two-phase, or quarter-phase relationship. Then if the terminal *d*, of one choking coil be connected to the middle point *o*, of the other, the three remaining terminals *a*, *b*,



FIGS. 90, 91, 92.—CONVERSION OF DIPHASE TO TRIPHASE ELECTROMOTIVE FORCES.

and *c*, will have between them an approximate three-phase electromotive force. For, if we lay off, as in Fig. 90, two lines *a o c* and *d b*, mutually perpendicular, but not connected, we have the electromotive force diagram corresponding to the circuits

of Fig. 89, before connecting the points, *d* and *o*. In Fig. 91, we have the corresponding electromotive force diagram for the condition after the points *d* and *o*, have been connected, and by joining the points *a*, *b*, and *c*, of Fig. 91, by straight lines, we obtain the triangle *a b c* of Fig. 92, in which the E. M. F.'s are, approximately, in three-phase relation, *a c* being 1,000 volts at standard phase, *a b* being 1,118 volts, and *b c*, being also 1,118 volts. In order to have a correct three-phase relation between the terminals *a b c* of Fig. 92, and of the choking coils in Fig. 89, the three E. M. F.'s must form an equilateral triangle, and this could be effected by making the E. M. F. supplied to the choking coil *b d*, 866 volts instead of 1,000.

The same transformation would be effected if, instead of connecting the

terminal of one choking coil to the mid-point of the other, each choking coil were associated as a primary with a corresponding secondary coil in a transformer, and the secondary coils were interconnected, with the end of one secondary to the mid-point of the other. The three remaining secondary terminals would then present a triangular system of electromotive forces, which might readily be adjusted to three-phase relationship.

Conversely, a three-phase set of E. M. F.'s, such as those produced at the receiving end of a three-phase transmission line, may be caused to produce two-phase E. M. F.'s by connecting two transformers, or two choking coils, as indicated in Fig. 91, the three external connections, *a*, *b*, *c*, receiving the three-phase transmission wires, and the terminals *a c* and *o b*, supply-

ing the two-phase,. converted E. M. F.'s, either directly from choking coils, or indirectly through secondary windings associated with these choking coils; *i. e.*, transformers.

CHAPTER XIII.

ALTERNATING-CURRENT TRANSMISSION LINES.

ELECTRIC power is now carried in commercial service by alternating currents in California as far as 240 miles. The distance to which power can be economically carried from waterfalls depends mainly upon the price of fuel at the point of delivery. Long-distance transmission is always carried out by the triphase system, since this system requires less weight of conductor for a given voltage between the wires, than any other. Through the open country the high-pressure wires are carried on poles, the wires being usually two or three feet apart. The voltage, between lines, averages about 600 volts per

mile of transmission distance; thus, a transmission over a distance of 40 miles might be expected to call for a pressure of 24,000 volts between any pair of three-phase transmission lines. This rough rule, which represents an average value obtained from numerous actual high-pressure transmissions, is not to be relied upon for distances exceeding 50 miles. The highest pressure hitherto employed is 60 kilovolts between lines. The limits to which high pressure can be carried depend to some extent upon climatic conditions. High-pressure insulators are either of porcelain or glass. They are generally of the "*double*"- or "*triple-petticoat*" type, and of large size, 7.5″ being a common diameter with 50-kilovolt lines. Fig. 93 shows a type of glass insulator.

The materials for overhead transmission

wires are always either copper or aluminium. The wire is usually stranded in sizes above 100,000 circular mils in area.

FIG. 93.—TYPE OF HIGH-TENSION GLASS INSULATOR.

An aluminium wire, for the same conductivity, weighs just about half as much as a copper wire, so that a copper wire

weighing 800 lbs. per mile would be represented electrically by aluminium wire weighing 400 lbs. per mile, the conductivity of aluminium wire being 60 per cent. of that of copper, referred to equal volumes. This relative lightness of aluminium wire permits not only of an easier transport, but also of placing the supporting poles at a greater distance apart. On the other hand, the diameter of an aluminium wire having the same conductance as a copper wire, is about 27 per cent. greater. Consequently, aluminium wires are not employed at the present time in underground conductors. The tensile strength of an aluminium wire having the same conductance as copper wire is only about 63 per cent. of the tensile strength of the latter, and while the tensile strength of aluminium is usually about 33,000 lbs. per square inch, it has

hitherto been necessary to support the wire in such a manner that the maximum working stress shall not exceed about half that amount.

With long high-pressure circuits the capacity of the line introduces a very noticeable charging current. This current is a *leading current*, or is ahead of the generator pressure in phase, and has a large wattless component. It often happens that as the load is applied at the receiving end of a long line, the current at the generator remains sensibly constant, but the power-factor increases, until, at full load, the current supplied by the generator is nearly in phase with the E. M. F. at generator terminals. In some long transmission lines, the line current actually diminishes to a slight extent as the load is increased.

An alternating-current circuit possesses both capacity and inductance. As already observed, the capacity tends to produce a current leading the working E. M. F. The system of insulated wires separated by air acts as an electric condenser, and this condenser is charged and discharged at each alternation of pressure or current. No appreciable amount of energy is expended in this process beyond that due to the passage of the charging current through the resistance of the line wires.

On the other hand, however, the inductance of a circuit is due to the magnetic flux which is linked with the loop of transmission lines when the loop carries a current. Each alternation of current in the lines involves an alternation or reversal in the direction of the magnetic flux

linked with the wires. The establishment of this alternating magnetic flux calls for a magnetizing current which lags behind the working E. M. F. in the circuit. The magnetizing current has a large wattless component, and requires no appreciable power beyond that due to the passage of the magnetizing current through the resistance of the line.

The coexistence of capacity and inductance currents on the line brings about some remarkable effects, which are usually of negligible importance in practice, but which occasionally become magnified to an extent that makes them readily observable. When an alternating E. M. F. is connected to a condenser or capacity, and to a choking coil or inductance, in simple series, then, at a certain relation between the frequency of alternation, the capacity,

and the inductance, the circuit becomes *resonant*, and the current which passes through the circuit may be many times greater than that which will flow under other conditions. In the case of a transmission line, the capacity and inductance are not connected in simple series, but are both distributed along the line in such a manner that there is a partial series connection between them, and a tendency to produce a partial resonance under certain conditions. The voltage at the receiving end of the line tends to become greater than the voltage at the generator terminals, particularly at light load. Moreover, the voltage and current at intermediate distances, although stationary in value at any one point, tend to vary from point to point in a manner resembling a series of stationary waves. The conditions necessary to establish a marked resonant condi-

tion in long transmission lines are high pressure, great length of line, and high frequency. With the ordinary low frequencies employed in transmission, the resonant effects are usually too small to be noticeable. Occasionally, however, some particular wave shape of alternating E. M. F. will act as though a high-frequency E. M. F. were superposed upon the low frequency of the generator, and may produce perceptible resonance, detected by a variation of voltage and current from point to point along the line, especially at light loads, and producing maximum voltage at the receiving end.

Whenever an electrical disturbance takes place in a long-distance transmission circuit, such, for example, as would be produced by connecting a generator to a circuit, or by varying the load, a succession

of waves of voltage and current will be set up in the circuit, which move to and fro, from one end of the circuit to the other, and steadily diminish in intensity, so that after a few oscillations, in a fraction of a second, they practically disappear. Such natural alternations or oscillations in the circuit, due to disturbance of its electric condition, are commonly called *surges.* The magnitude or intensity of such surges depends upon the magnitude and suddenness of the electric disturbance. The most effective means of producing a sudden and powerful electric disturbance, capable of creating powerful surges, is to produce a short circuit in the transmission lines, whereby an unduly powerful electric current will flow through them, and then to interrupt this short-circuit very suddenly, at an instant when the alternating-current waves are at a maximum or

crest. Such surges are apt to be accompanied by momentary electromotive forces far in excess of those which are used in the operation of the line. This is particularly the case with overhead or aërial line circuits. The magnitude of the surge *E. M. F's.* is practically unaffected by the length of the transmission line. Care should, therefore, be taken to avoid short-circuits on transmission lines, as far as possible, and if such short-circuits occur, to avoid suddenly interrupting them, especially if underground wires are connected with overhead line circuits, since the high pressures momentarily developed in the surges may puncture the insulation of the buried wires.

The inductance of alternating-current circuits tends to increase the drop of pressure which occurs in them with the pas-

sage of a given current strength. Thus, if a circuit has a resistance of one ohm, then an alternating current through the circuit of 100 amperes always produces a greater drop than 100 volts—commonly 120 volts—and in extreme cases the drop may be several times as great. This effect depends upon the frequency of the alternating current, and to a slight extent also upon its wave form. With overhead transmission-wires it depends upon the distance between the wires, and the further the wires are apart the greater will be their inductance and the drop of pressure in them, although not in direct proportion. In power circuits, where alternating currents are converted into direct currents for electric railways by the use of converters, the inductance of the line often plays a useful part in aiding the automatic regula-

tion of the converters under variations of their load.

The inductance of a wire may be greatly increased by running it through an iron pipe, and the drop of pressure in a single conductor which passes through an iron pipe and carries an alternating current of fairly high frequency, may be very great. When alternating-current wires have to be carried through iron tubes, two wires forming the going and return conductors are laid side by side in the same tube, whereby the inductance is much reduced.

CHAPTER XIV.

SYNCHRONOUS MULTIPHASE MOTORS.

A SYNCHRONOUS multiphase motor differs from a synchronous single-phase motor by reason of the fact that when connected at rest to its alternating-current mains it develops a starting *torque*, or tendency to rotate, in one direction, whereas the single-phase synchronous motor has no tendency to start in either direction, when connected with the mains, but develops, on the contrary, a locking tendency, or negative starting torque, and may be started with equal facility or difficulty in either direction. The starting torque of the multiphase synchronous motor is, however, only

a small fraction of the full-load torque, and is only obtained at the expense of a relatively powerful starting current. Consequently, multiphase synchronous motors cannot be started when connected to their full load, or with a load which requires nearly as much torque to overcome at low speeds as at full speed.

A synchronous multiphase motor is practically identical with a multiphase generator. As soon as it reaches the speed of synchronism, it acquires its full torque or full rotative effort, and will usually stand a large overload without pulling out of synchronism. When the load is of such a character as will admit of being readily connected to, or disconnected from the motor, and where the load once connected requires to be steadily run for long periods of time without stopping, the synchronous

motor possesses distinct advantages. Its power factor can be varied within fairly wide limits by adjusting the excitation of its field magnets. These are usually excited by a small direct-current generator driven by the motor itself. If the excitation is increased, the E. M. F. of the armature is increased, and the phase of this E. M. F. is automatically shifted in such a manner as to take the required power from the transmission circuit. This in turn produces a shifting in the phase of the received current, so that with powerful motor-field excitation the received current tends to lead the generator pressure, while, with weak field excitation, the received current tends to lag behind the generator pressure. At a certain intermediate excitation of the motor field, the currents in the motor circuits will be in phase with the generator pressure, and

FIG. 94.—1000-HP. DIPHASE SYNCHRONOUS MOTOR, WITH REVOLVING FIELD.

the currents will be at nearly their minimum magnitudes, or the circuit will develop the non-inductive condition of unit power factor (100 per cent.). Consequently, synchronous motors possess the advantage of being able to adjust within certain limits the power factor of the circuit to which they are connected, and in this way they may aid the generator in output and regulation.

On the other hand, synchronous motors are entirely unsuited to the condition of frequent starting or stopping, and when intermittent service is required, multiphase induction motors have to be used.

A 1000-HP. diphase synchronous motor with revolving field is shown in Fig. 94. The revolving field, or rotor, is provided with 40 poles, so that the arma-

ture, or stator, also develops forty poles upon its internal surface under the influence of the two-phase currents it receives. The field is excited by a continuous current supplied through the pair of slip rings *R*. In order to avoid having to supply the very powerful starting currents, which would be necessary in order to bring this machine from rest up to speed, a small diphase induction motor *M*, is provided with a clutch, whereby the supply of relatively feeble two-phase currents to the induction motor, will enable this motor to bring the main motor up to speed through the clutch and gearing *G*.

Multiphase synchronous motors are either two-phase (diphase or quarter-phase) or triphase (three-phase). The only difference between these two types lies in the arrangement of armature conductors and

circuits. In either case, the conjoint action of the multiphase currents received in the armature produces therein a system of multiphase magnetic poles, steadily revolving around the armature surface. Thus the machine of Fig. 94, develops 40 magnetic poles in its stationary armature; *i. e.*, 20 north poles, and 20 south poles, mutually interspersed. These poles are always present, and steadily rotate around the inner surface of the armature. At the normal speed of synchronism the 40 directly excited field-poles of the rotor follow the 40 travelling poles set up by multiphase currents in the stator, just as though they were respectively connected by elastic bands to these travelling poles.

The efficiencies of synchronous motors are practically the same as those of multi-

phase generators. These machines being synchronous, their speed is necessarily constant under all variations of load within their capability, provided that the speed of the generator is constant.

CHAPTER XV.

CONVERTERS.

In order to locate a central power station at the point where fuel or water-power can be obtained most cheaply, it is generally necessary to transmit the power by alternating currents from the power house to the point of consumption. When the electric power has to be delivered in the form of continuous currents, as for electric railways, or electro-chemical purposes, it is necessary to convert the alternating currents received from the transmission lines into continuous currents. For this purpose a *converter*, often spoken of as a "*rotary converter*," is employed.

A converter consists essentially of a direct-current machine having its armature tapped at magnetically equidistant points either for the reception or delivery of multiphase alternating currents. Such a machine is, therefore, provided with a continuous-current commutator, on the direct-current side of its armature, and a set of collector rings on the alternating-current side. When alternating currents are supplied through the collector rings, the machine is operated as a synchronous multiphase motor, while direct currents may be collected from the brushes on its commutator. During its operation, under these conditions, the armature acts to a certain extent as a revolving commutator, whereby the alternating currents received on one side pass almost directly across the armature into the brushes on the commutator. The same type of machine, if driven by

power, becomes a *double-current generator;* *i. e.*, becomes a generator capable of delivering both direct currents and alternating currents simultaneously.

A typical triphase converter of 300 KW. capacity is represented in Fig. 95. The vertical field frame carries six field-poles surrounding the armature. The armature carries the three collector rings *R*, on one side, and a commutator *C*, on the other side. The three collector rings are connected to points on the armature 120 magnetic degrees apart; *i. e.*, 120 actual degrees for a bipolar armature. If alternating currents are supplied to the three collector rings *R*, with 330 volts between any pair of brushes, the brushes on the commutator *C*, will deliver a direct-current pressure of, approximately, 550 volts. The speed of rotation of the armature is con-

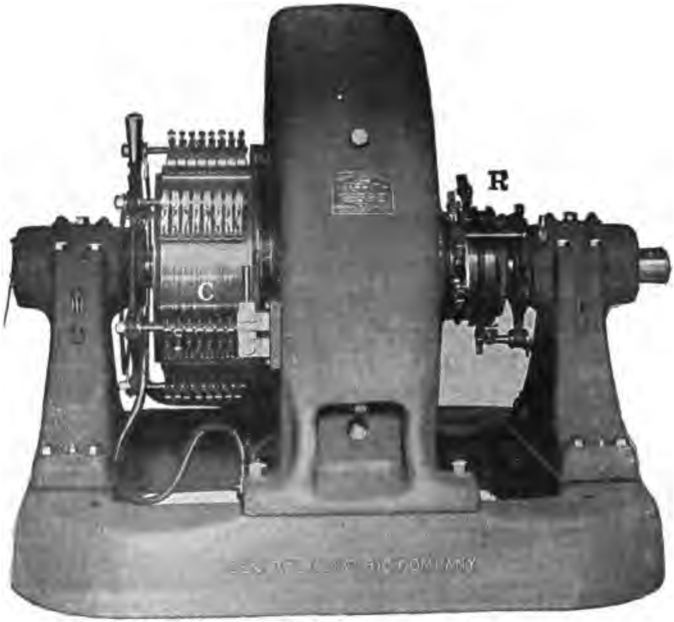


FIG. 95.—300 KW. TRIPHASE CONVERTER.

stant, and is the speed of the machine considered as a synchronous triphase motor. The field winding of the machine

is supplied from the commutator or direct-current end.

A converter is equivalent to a *motor-generator*, or the association of a direct-current generator driven by a separate alternating-current motor. In some respects, however, the converter is superior to a motor-generator. Thus, the full-load efficiency of a large converter is usually nearly 95 per cent., whereas the combined efficiency of a motor-generator of equal capacity is usually only about 87 per cent. On the other hand, however, step-down transformers have to be employed with converters, in order to supply to them the right voltage for conversion. In compactness, in freedom from sparking, and in the power of carrying over-loads, the converter is decidedly superior to the motor generator.

Converters are constructed for receiving two-phase, three-phase, and six-phase currents, and converting the same into continuous currents. The efficiency of conversion increases with the number of multiphase currents, and, in large sizes, six-phase converters are, therefore, preferred, in spite of their greater complexity. Six-phase currents are supplied from three-phase lines by using two secondary coils on each of the three triphase transformers supplying the alternating currents to the converter. The two sets of three-phase secondaries, each differing in phase by about 120°, are then connected with six collector rings on the converter in such a manner as to supply six currents differing in phase by 60°.

Converters are started from rest, either as synchronous multiphase motors from

the alternating-current side, or, where a number are operated in parallel, the first may be started as a synchronous motor, and the remainder started as direct-current motors from the direct-current side of the first. In some cases a small multiphase induction motor is placed on the armature shaft of the converter, so as to enable the machine to be started from rest by its aid. This has the advantage of requiring much less current from the lines than would be necessary to start the machine as a synchronous motor.

Such a machine is represented in Fig. 96. *M*, is the induction motor for starting the armature from rest, and for bringing it up to synchronous speed. The alternating-current terminals are partly seen at *A′*, while the armature *AA*, rotating in a 16-pole field, carries the commutator *C*,

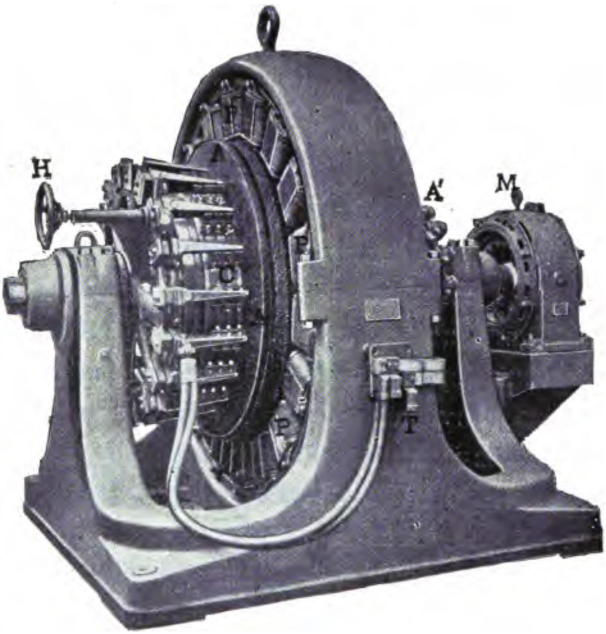


FIG. 96.—500 KW. ROTARY CONVERTER WITH STARTING MOTOR.

from which a 16-brush set, controlled in position by the handle *H*, delivers a continuous current to the railway bus-bars.

T, is one of the main direct-current terminals. The field windings P, are supplied partly in shunt, and partly in a series winding. The ends of the latter are seen at T.

A diphase converter has its alternating-current terminal voltage, approximately, 70 per cent., of its voltage at the direct-current terminals, and a triphase or six-phase converter has its alternating terminal voltage, approximately, 60 per cent. of its voltage at the direct-current terminals. Since the voltage on the direct-current side of the machine is thus, approximately, determined by the voltage supplied to the alternating-current rings, it is necessary that the alternating-current pressure should be maintained nearly constant under variations of load, if the apparatus has to maintain constant direct-current

pressure without either compounding or hand regulation. A hand regulation of the exciting current will vary the converted pressure within certain limits, by varying the electromotive force of the machine considered as a synchronous multiphase motor. Converters are, however, frequently successfully compound-wound on the direct-current side, whereby they become enabled to maintain approximately constant direct-current pressure when supplied through a fairly long alternating-current transmission line and step-down transformers.

CHAPTER XVI.

RECENT PROGRESS IN INDUCTION MOTORS.

During the last few years great advance has been made in the design and application of multiphase induction motors. These machines have already been described in Chapter IX. Induction motors are now constructed up to sizes of 1200 HP. These machines are characterized by great simplicity and solidity of structure, being devoid of a commutator and often entirely devoid of brushes. Under ordinary conditions of operation, their speed is nearly constant between no-load and full load, the *slip*, or frictional drop in speed under load, of these machines being

usually 2 or 3 per cent. at full load in sizes of 20 HP, diminishing to about 1 per cent. or less in large sizes. Owing to the fact that they are not quite synchronous, they are sometimes called asynchronous motors.

Multiphase induction motors are either two-phase or three-phase. In either case the *armature*, or that element connected with the transmission lines, usually called the *primary element*, develops upon its active surface a series of alternating magnetic poles, and these poles rotate in magnetic synchronism with the generator rotor. That is to say, a rotating magnetic field is developed on the surface of the motor armature by the conjoint action of the multiphase alternating currents. The *secondary element* of the motor consists essentially of a set of short-circuited

windings, which being subjected to the influence of the rotating magnetic field in the primary, have powerful alternating currents induced in them. The rotating magnetic poles of the primary pull upon these induced currents and drag upon the secondary member, thereby setting the rotating element of the motor in motion. As ordinarily constructed, the primary element is an external stator, and the secondary element is an internal rotor.

The primary of a 150 HP. Westinghouse induction motor is shown in Fig. 97. It consists of a number of copper bars occupying slots on the inner surface of a hollow ring of laminated steel. These copper bars are carefully insulated, and are connected in series in such a manner as to provide two circuits, or sets of circuits, for a two-phase motor, and three circuits,

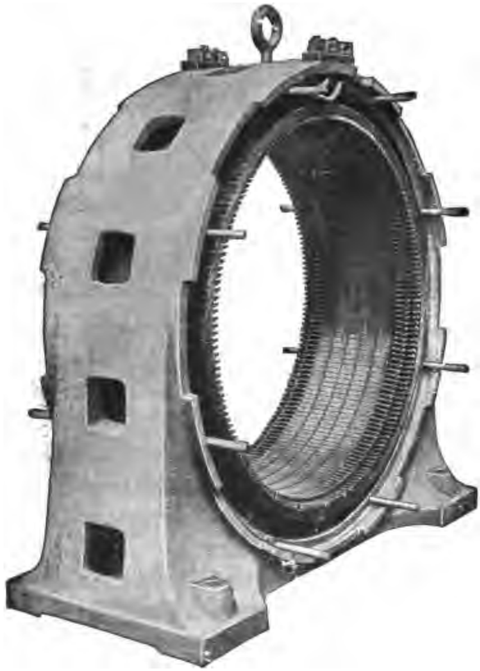


FIG. 97.—PRIMARY FOR A 150 HP. WESTINGHOUSE INDUCTION MOTOR.

or sets of circuits, for a three-phase motor. These circuits, when energized by

the requisite multiphase currents, develop a constant even number of alternate magnetic poles, revolving or progressing around the inner surface of the ring stator. The secondary element of this motor is represented in Fig. 98. It consists of a hollow cylinder of laminated steel, with slots cut in its surface. These slots are undercut, so as to form tunnels below the surface of the cylinder, the roof of each tunnel being cut by a single groove.

In many European types of induction motors, the tunnels are brought very close to the surface of the cylinder, but remain uncut. In each slot is placed one or more stout bars of copper, and these bars are securely bolted at each end to a metallic ring on each side of the armature. This structure constitutes the secondary short-circuited member, and from its resemblance to a squirrel-

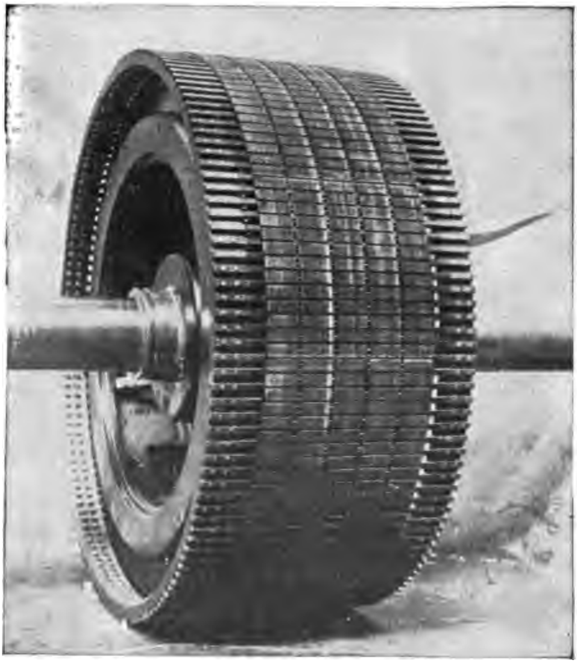


FIG. 98.—150 HP. WESTINGHOUSE INDUCTION MOTOR SECONDARY.

cage, is often referred to as a "*squirrel-cage*" structure. All the conducting bars

being in parallel between the two end-rings, the resistance of the secondary circuit or circuits is necessarily very low, and the E. M. F. induced therein is also very low, while the strength of the induced currents is correspondingly great. The course of the induced currents is in loops, each, broadly speaking, surrounding the poles which are formed upon its surface, the currents being thus directed to the right, and to the left, across the surface of the secondary, in successive groups. This distribution of poles and currents rotates over the surface of the secondary element at the speed of slip, so that at synchronism, if it could be actually obtained, the induced system of multiphase poles and currents while rotating in space, at the same speed as the poles in the primary element, would be stationary with reference to the surface of the rapidly rotating secondary element. The

bar construction forming the secondary winding is also shown in greater detail, for another secondary member, in Fig. 99.

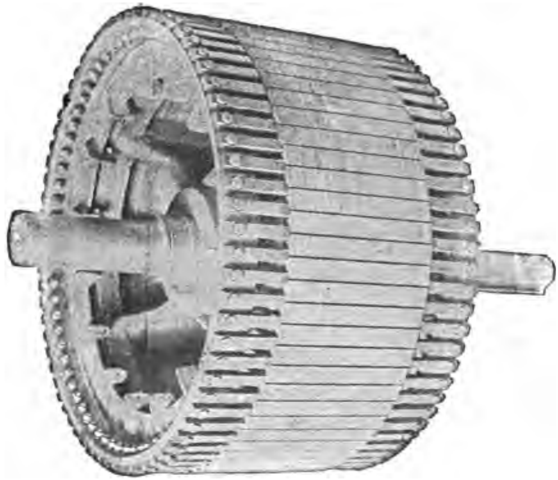


FIG. 99.—SECONDARY COMPLETE, SHOWING COPPER BARS CONNECTED TO END RINGS.

The completely assembled motor is shown in Fig. 100. The bearings are carefully adjusted so as to maintain a very small clearance or air-space between the active

FIG. 100.—150 HP. WESTINGHOUSE INDUCTION MOTOR COMPLETE.

surfaces; *i. e.*, the inner surface of the stator primary and the outer surface of the rotor secondary. The narrower

this clearance, the smaller will be the strength of primary current required to magnetize the machine, and develop the rotating magnetic field, other things being unchanged.

One of the objections to the alternating-current motor is the relative magnitude of the magnetizing or wattless current which it needs for its operation, and which is practically independent of the load or working current of the motor. The magnetizing currents are largely out of step with the working pressure in the motor circuits, or have a large wattless component; consequently, the power-factor of the motor is rendered comparatively small at light loads by their presence. One of the improvements effected in the design of induction motors, in recent years, has been the reduction of the air-gap by skillful

mechanical construction, so that the power-factor of these motors has been increased at all loads; or, in other words, the magnitude of the wattless exciting components has been reduced, while the active or working currents, *i. e.*, the components in phase with the working pressures, have remained the same.

In the starting of such a motor from rest by connection to the multiphase mains, the frequency of the secondary currents is initially the same as the frequency of the primary currents, since the machine, while at rest, is virtually in the condition of an ordinary transformer. Under these circumstances the reactance of the secondary circuits is relatively large, and the secondary currents and set of poles are largely displaced in phase, or shifted from the best positions for the development of a torque. Consequently, the starting torque

of such a motor is relatively very feeble when the secondary circuits are completely short-circuited, in spite of the fact that both the primary and secondary starting currents are unduly powerful. In order to aid the starting torque and, at the same time, to reduce the starting currents, the end-rings are given such material and dimensions as to offer a relatively appreciable secondary resistance, thereby tending to diminish the *reactance factor* of the circuit, or the ratio of reactance to resistance, as well as the strength of the starting currents. This improvement in the starting conditions is obtained at some sacrifice to the best conditions of efficiency and speed-regulation at full-load and speed, when the frequency of the secondary currents is that of the slip, or only one or two per cent. of the frequency in the primary circuit, and when undue resistance is wholly prejudicial.

In order to improve the condition at starting while maintaining the best conditions for full speed, secondary resistances, which are large by comparison with the resistances of the secondary windings, are often inserted by some form of switch into the secondary circuits, whereby the full-load torque can be obtained at starting, with the normal full-load current. After full-speed has been obtained these external resistances are short-circuited, and cut out of circuit, thereby producing the best conditions for full-speed running. In most cases these external resistances are built into the structure of the rotating secondary; a collar sliding along the shaft of the rotor being employed to cut the starting resistances in or out, as required. Fig. 101, represents an armature of the triphase motor containing starting resistances. With the aid of

such resistances the motor can be started from rest with full-load torque and without any overload of current, when full

FIG. 101.—ARMATURE WITH STARTING RESISTANCE.

pressure is connected to the primary terminals. This construction necessitates some extra complication in the secondary, since the bars of the winding, instead of forming a simple squirrel-cage, have to be connected in series or groups, like the winding of the primary, in order to form

definite circuits into which the external resistances can be introduced.

With the squirrel-cage construction of secondary, the starting is usually effected by reducing the pressure at primary terminals. This has the effect of reducing the strength of the starting currents in the various circuits, and at the same time, an adequate starting torque is developed with the aid of the permanently inserted resistance in the secondary windings. The usual method of reducing the pressure at primary terminals at starting, is to introduce a set of reactance coils or choking coils in the primary circuits, and to tap off a portion of these coils to the motor terminals. A form of starting device or *auto-starter* for accomplishing this result is shown in Fig. 102. This starting box contains a pair of choking

FIG. 102.—STARTING DEVICE.

coils suitable for use with a two-phase circuit and motor. When the four switch-handles are thrown down on one side, the two middle switchblades close the primary circuit upon the choking coils, while the two remaining blades connect the motor terminals with the requisite portions of the choking coils to supply the reduced E. M. F. After the motor has in this manner been brought up to speed, the four switches are thrown over on the opposite side. This has the effect of disconnecting the choking coils, and also of connecting the motor terminals directly to the primary mains.

The efficiencies of multiphase motors are, approximately, the same as those of direct-current motors of equal size. The regulation in speed is also about equally good. The induction motor is a much

simpler machine than the direct-current motor and less liable to derangement or burning-out by overload. It also requires less careful inspection for the same reason. When operated at variable speeds, however, as in elevators, hoisting, and railway work, the induction motor is distinctly inferior to the direct-current motor, owing to its relatively large magnetizing current, its relatively feebler torque, and the relatively great current required to supply that torque.

Induction motors in small sizes can be operated from single-phase circuits when multiphase mains are not available. For sewing-machines and other apparatus requiring but little power, they can be started by hand in the required direction, after which they accelerate and come up to full speed. Such motors are used in

quarter horse-power and half horse-power sizes. They develop a single-phase magnetic field and are devoid of starting torque until given an impulse by hand in the required direction. In larger sizes up to 7 1/2 horse-power, such machines are started from rest by providing their primary with two circuits which are connected in parallel with the single-phase mains, but the phases of the currents in the two circuits are caused to differ by the insertion of a condenser or resistance in one of the branches. By this "*split-phase*" method, an approximation to the two-phase rotating field is established in the primary, which enables the motor to start, and after speed has been obtained, the auxiliary circuit is disconnected and the apparatus operated as a single-phase motor.

CHAPTER XVII.

TURBINE ALTERNATORS.

PRIOR to the development of the dynamo-electric generator, steam engines were constructed almost invariably of the slow-speed reciprocating type. In order to attain the speeds of rotation required by dynamos, it was necessary to employ belts operating over very large engine pulleys and very small dynamo pulleys. In order better to meet this requirement, the speed of reciprocation of dynamo-driving engines was raised, and a new type of high-speed engine was thus developed.

Quite recently, however, a new class of steam engines has been produced, namely,

steam turbines. These engines are rotary instead of reciprocating, and are therefore peculiarly adapted to the propulsion of rotary devices like the rotors of dynamos. The speeds of rotation of steam turbines are very high by comparison with those of reciprocating engines of equal power. Consequently, the dynamo has had to adapt itself to the increased speed of rotation, and a special type of alternator has come into use called a *turbo-alternator* or *turbine alternator*.

The advantages of turbine units over reciprocating engine units are economy in material with simplicity and ease of operation, high efficiency at small loads and good efficiency at full or extra loads. As regards economy in material, the weight of a 5,000 KW. turbine unit is about eight times less than that of a 5,000 KW. engine

unit. The floor space occupied by a turbine unit is likewise several times less than that of an engine unit, thus reducing the cost of land and buildings for a power plant. The turbine runs with practically inappreciable vibration and without any reciprocating thrust. Consequently, the foundations necessary for its support are much lighter and need only be those required for supporting its dead weight. The number of parts in the mechanism of a turbine unit are much fewer than in that of an engine unit and thus the amount of inspection, oiling and cleaning required is much reduced in the former.

The increased speed of rotation of the dynamo in a turbine unit is also attended with economy in material for its construction, at least up to a certain limit. Thus, if a 5,000 KW. engine unit makes

75 revolutions per minute, the rotating field-magnet system will have 40 poles in order to generate an alternating current of 25 cycles per second ($25 \times 60 = 1{,}500$ cycles per minute $= 3000$ alternations per minute $= 75$ r. p. m. $\times$ 40 poles). If the speed of a 5,000 KW. turbine unit is 500 revolutions per minute, the number of poles in the revolving field-magnet system will be reduced to 6, in order to produce the same frequency. Moreover, the quantity of magnetic flux required to pass through each pole will be reduced as the speed of rotation increases; so that a smaller cross-section and reduced size of construction will be needed. Consequently, while engine-driven alternators commonly deliver 10 to 12 watts per pound of alternator weight, turbine alternators commonly deliver 15 to 25 watts per pound of total weight in turbine and alternator combined.

Turbine alternators differ from engine alternators in the number of poles, in diameter of rotor, and in their details of construction, with a view to the high speeds of rotation. In any uniformly revolving wheel, the centrifugal force on any single small part varies directly as the distance of the part from the axis and also directly as the square of the speed of rotation in revolutions per minute. Any piece at a distance of one foot from the axis will exert a centrifugal force 340 times its own weight, when running at a speed of 1,000 revolutions per minute. At a speed of, say, 3,000 revolutions per minute, the force would be nine times greater, or 2,160 times its own weight, so that on each pound of material revolving at this speed and radius the centrifugal force is about the weight of one ton.

There are two principal types of turbine

manufactured in the United States at the present time, namely, the Parsons turbine and the Curtis turbine. The former is of the horizontal drum type and the latter of the wheel type, with its axis vertical, except in smaller sizes.

A Westinghouse-Parsons 1,500-*KW.* turbine unit is shown in Fig. 103. The al-

FIG. 103.—WESTINGHOUSE-PARSONS 1500-KW. TURBO-ALTERNATOR.

ternator is placed at the end of the machine opposite to that at which the steam enters. Fig. 104 gives a view of a rotor in process of being wound. This rotor is bipolar and

is a steel cylinder slotted with grooves to receive the insulated field winding. A pair of collector rings serve to supply a direct

FIG. 104.—ROTOR BIPOLAR FIELD IN PROCESS OF WINDING.

current for the magnetic excitation of this winding. A stator armature is shown in Fig. 105.

Fig. 106 is a general view of a 5,000 KW.

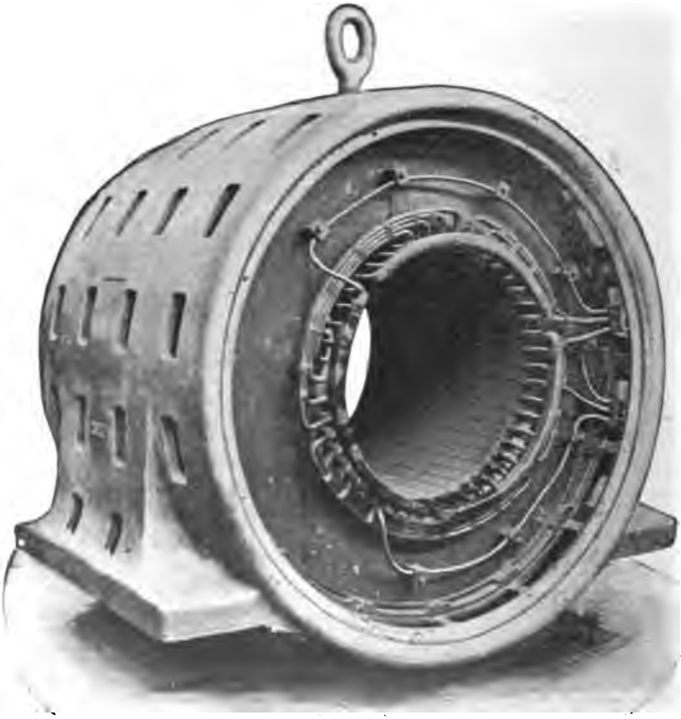


FIG. 105.—STATOR ARMATURE OF THREE-PHASE TURBO-ALTERNATOR.

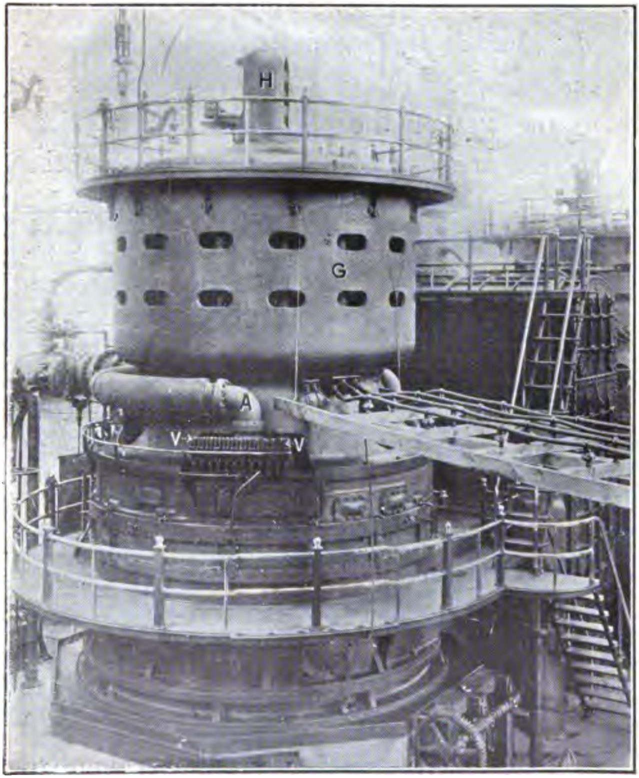


FIG. 106.—5000-KW. CURTIS TURBO-ALTERNATOR.

Curtis turbine unit. The main steam pipe *A*, admits steam through the governor-controlled admission-valve mechanism *VV*, to the top of the turbine. The vertical turbine shaft runs into the hood *H*, at the top of the machine, carrying a rotor field-magnet within the generator frame *GG*. This frame supports a stator armature, resembling that of Fig. 105 when turned on its side. A field-magnet system of six poles is shown in Fig. 107. Here the field-magnet coils are held in place by the polar projections and also by the intermediate wedges of non-magnetic material.

As the free-cooling surface of a large turbine-alternator is much smaller than that of the ordinary engine-alternator of equal power, special precautions are taken to provide ventilating ducts in the field, arm-

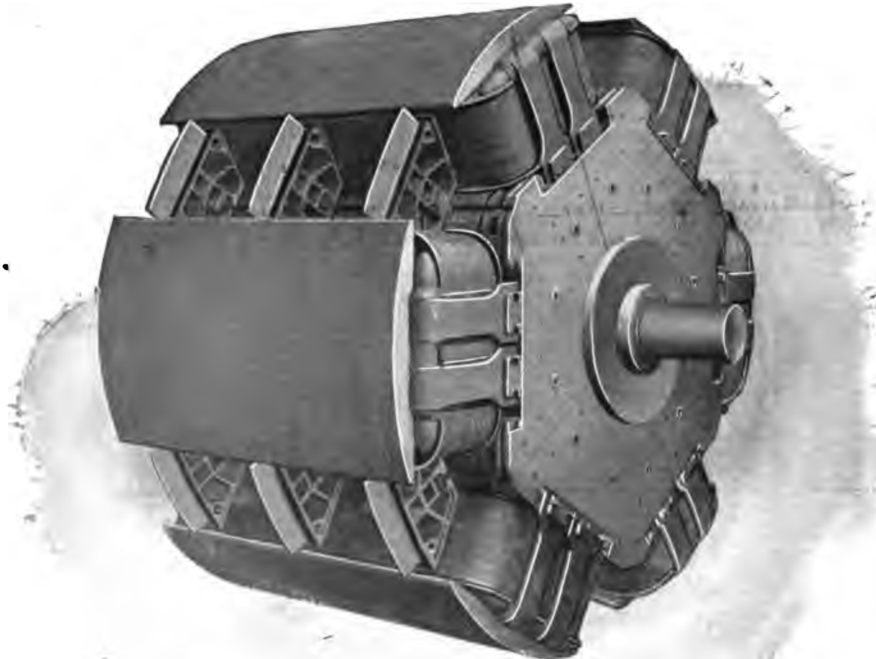


Fig. 107.—Revolving Field for a 5000 KW. Alternating-Current Turbine Generator.

ature and frame of a turbine alternator, in order that the air driven through these ducts by centrifugal force, when the machine is in operation, may keep the apparatus sufficiently cool.

CHAPTER XVIII.

ALTERNATING-CURRENT TRACTION MOTORS.

THE development of the multiphase alternating-current motor along the lines outlined in Chapters IX and XVI, has made possible the use of multiphase alternating-current motors to street-car and electric railway car propulsion. Since long electric railroads are usually supplied with high-tension alternating currents from power houses to substations along the route; where converters or machines with rotating commutators change the alternating currents into direct currents for delivery to the cars, these converters could be eliminated and replaced by stationary trans-

formers, if the cars had motors capable of being operated by alternating currents. On the other hand, there are objections to the use of multiphase motors for electric traction. In the first place, such a multiphase motor requires at least three electric supply conductors. Counting the track as one conductor, there must be two trolley wires or equivalent supply conductors independent of the track. Consequently the use of multiphase motors would involve reduplicating all trolley wires. Trolley wires are sufficiently troublesome and unsightly when single, and the prospect of doubling them does not meet with favor.

Moreover, the multiphase induction motor is essentially a constant-speed motor; that is to say, it tends to run slightly below synchronous speed. It works at a disadvantage and inefficiently, when operated

at varying speeds as well as varying loads. Nevertheless, it is very necessary that a street-car motor should be capable of being effectively operated, not only at varying loads, but also at varying and regulated speeds.

Mainly for the above reasons, the multiphase alternating-current motor has not come into use for traction purposes in America, although it has been adopted to some extent on European electric railroads.

Within the last few years, however, a type of single-phase series alternating-current motor has been developed suitable for traction purposes. It has a commutator and brushes and bears superficial resemblance to an ordinary direct-current series motor. The principal difference between these two motors is that whereas in the

direct-current motor the magnetism in the field poles is constant in direction, in the alternating-current motor the magnetism reverses in the field-poles and field-cores at each alternation of the current. For this reason the field-magnet cores of the alternating-current motor are laminated, as well as the armature cores. That is to say, the entire magnetic circuit of an alternating-current series motor has to be laminated or split into sheets; whereas, in the direct-current series motor, only the armature-cores and the faces of the field poles are so laminated.

Alternating-current series motors are capable of being operated on direct-current circuits. This makes it possible to install a complete alternating-current traction system from generator to motors in the suburbs of a city and to operate the same

car on a direct-current system that may already have been installed within the city limits. This interchangeability involves, however, some additional complication in the circuit connections of the motor and of the car wiring.

Up to the present time the series alternating-current railway motor has shown itself to be somewhat inferior to the ordinary direct-current railway motor in efficiency, in pull for a given current and in current consumption. On the other hand, the use of the alternating-current railway motor reduces the cost of conductor and the cost of substation attendance in the system. It would seem that such a system was well adapted for long interurban railroads with infrequent trains, high speeds, and few stops.

CHAPTER XIX.

ALTERNATING-CURRENT SWITCHES AND SWITCHBOARD DEVICES.

THE steadily increasing voltage at which power has of late years been transmitted, as well as the increasing quantities of power transmitted by single circuits, have rendered increased attention necessary to the details of the switch mechanism controlling such circuits.

On circuits of 100 volts pressure, even the most powerful currents can ordinarily be started and stopped without difficulty by any form of switch which will make good contacts and offer sufficient metal in

the path of the current to keep from being overheated. When the pressure of the circuit is raised to 500 volts, powerful alternating currents broken at the switch are capable of producing vicious arcs and greater care must be given to the structure. When the alternating-current voltage is increased to several thousand volts, dangerous arcs may follow the opening of the switch in air and the design of the switch becomes difficult. At fifty kilovolts pressure it becomes extremely difficult to break a powerful alternating current quickly and effectively at the contacts of a switch opening in air. The arc obstinately persists, is dangerous to approach and is apt to produce a short circuit between the conductors.

For the above reasons, switches for circuits of 1,000 volts or over are now com-

monly made to open and close their contacts in oil. A film of oil is able to withstand a much higher electric pressure without breaking down in spark discharge than a film of air. Oil also much more quickly quenches and suppresses an alternating-current arc than air. It is possible to break alternating-current circuits under full load at oil switches, which at air switches would be almost impossible.

A form of three-phase oil switch is indicated in Fig. 108, as situated at the back of a switchboard, while the operating handle projecting beyond the face of the switchboard is seen in Fig. 109. Each of the three circuits is opened and closed in a separate oil tank *T*. The switch consists of a horizontal metal bar *y*, carried on an insulating rod *r*, and armed with a pair of conical contact points *c d*, which engage,

when the switch is closed, with fixed metal contacts *C* and *D*. The conductors

FIG. 108. FIG. 109.

WESTINGHOUSE THREE-PHASE OIL SWITCH. REAR AND FRONT VIEWS.

terminating at *C* and *D*, enter the box through the insulators *f* and *e*, respectively.

Each circuit is therefore interrupted at two gaps *Cc* and *Dd*, in series with each other and in oil.

The three switches are closed simultaneously by pressing down the handle *H*. A detent then engages with the handle and holds the three switches closed. If, however, an unduly powerful current should flow through the switches and their circuits, small transformers with their primaries in those circuits and their secondaries connected to the electromagnets *m m*, will actuate those magnets and release the detent, thus allowing the three switches to open simultaneously in the oil by gravity.

Another form of three-phase oil switch with the oil tank removed is shown in Fig. 110. The operating handle projects from the front of the switchboard while the switch contacts and wiring are behind it.

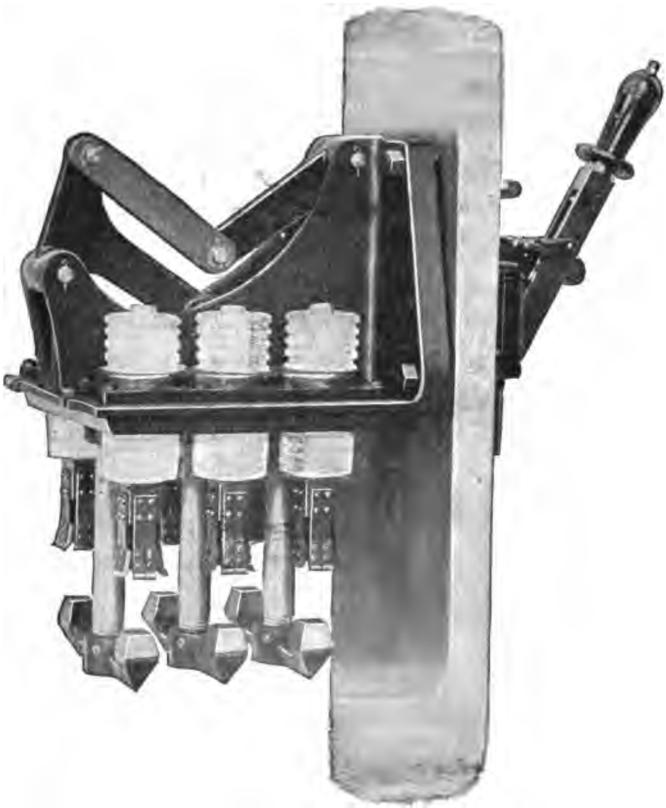


FIG. 110—OIL SWITCH ELECTRICALLY OPENED, CLOSED BY HAND.

When the circuits controlled by the switch transmit a large amount of power, so that the pressure and current are large, the oil-switch mechanism is too large to place near the operating gallery and is also too heavy to be readily operated by hand. In these cases each of the three component switches is worked in an oil tank and each oil tank is supported on insulators in a separate compartment of brickwork so as to smother flame in case of the oil catching fire. The three switches are connected mechanically to a common yoke which is lifted by a local electromotive device, either a small motor or a lifting electromagnet. After the contacts of the switch have been closed they may be quickly opened by an electromagnetically pulled trigger.

Figs. 111 and 112 show one of these large oil-switches. In Fig. 111 the switches

are at the open-circuit position. *A*, *B* and *C*, are the three oil tanks in which the contacts play. These tanks may be with-

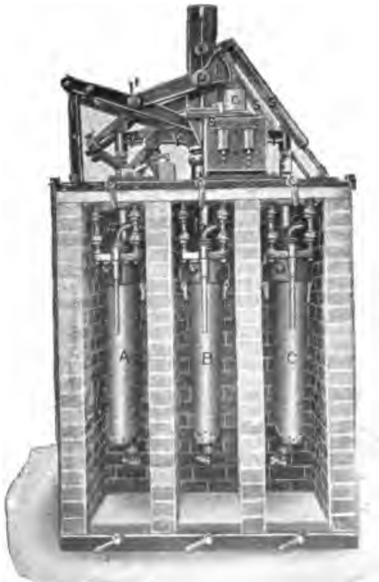


FIG. 111.—SOLENOID-LIFTED THREE-PHASE OIL SWITCH.

drawn from beneath at any time to permit an inspection of the working parts. The

level of the oil in these tanks is indicated on a glass gauge in front. The cable,

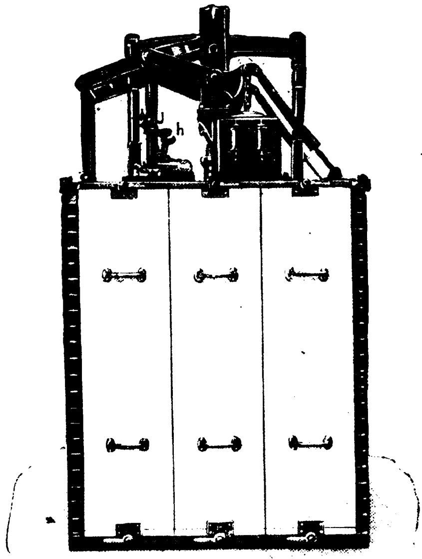


FIG. 112.—OIL SWITCH CLOSED AND WITH ITS COVERS IN PLACE.

connected with the stationary contacts, enter in pairs through insulators at the top

of each tank. The contact pieces are metal bars arranged in a manner partially resembling the construction of Fig. 110. Each contact bar is supported by an insulating rod which plays up and down through the cover of the tank. The three rods are fastened to a common yoke *Y*, *Y*, *Y*, above the soapstone slab which forms the cover of the three brick compartments. The yoke with its rods and other attachments forms a fairly heavy mechanical system, the weight of which tends to keep the switches at the open-circuit position as shown. When it is desired to close the switch, the operator at the switchboard, in some other part of the building, operates a small controller handle which closes a direct-current circuit from the switchboard through a large solenoid, or suction electromagnet, situated at *S*, Fig. 111. This solenoid attracts, or sucks in, its iron core

C, which pulls upon the end *l*, of a lever *ll′*, pivoted at *p*. The pull is aided by the spiral springs, *ss*. As the end *l′* lifts, it raises the yoke *Y*, *Y*, *Y*, and closes the three oil switches at the end of the stroke. Fig. 112 shows the apparatus with the yoke raised, the switches at their closed-circuit position and the iron doors of the brick compartments in place. After the switches have been closed, the yoke remains supported at its top position by the jointed rod *J*, thus relieving the solenoid of its duty. The rod *J*, has a toggle, which when struck by the hammer releases the yoke system and permits it to fall and quickly to open the switches below. The hammer *h*, is struck by means of tripping magnets, operated either by the controller at the switchboard, or by an overload relay connected with the main circuits. If the circuits carry an excessive current, the over-

load relay will be automatically called into action, so that the tripping magnets will release the toggle and open the switches, at the same time indicating the fact to the switchboard operator by the lighting of a lamp.

CHAPTER XX.

CONSTANT-CURRENT TRANSFORMERS.

EXCEPT in large cities, arc lamps employed for street illumination are most effectively and economically operated in series. In this manner a number of arc lamps can be connected in a single circuit, forming a loop from the central station several miles in length. Such circuits require a constant current-strength, or constant number of amperes for their operation, but the voltage necessary to maintain this current will vary with the number of arc-lamps in the series. The voltage must be subject to adjustable variation, in order that the constant current may be maintained.

Series-arc-circuits, *i. e.*, constant-current arc-circuits, require special generators for their operation, generators which will regulate and vary the voltage at their terminals in order to keep the current constant in the circuit. On the other hand, the generators which operate lighting circuits, motor circuits, railroad circuits—in fact nearly all classes of circuits outside those for series arc-lighting—require constant-potential generators, which will enable the voltage at their terminals to be maintained constant despite large variations in the strength of current they deliver.

Consequently, when a central station has to supply some series arc-lighting in addition to a general constant-potential distribution, it becomes necessary to install a special generator or generators for the

series arc lamps, and in most cases this will also require the installation of special additional engines to drive the constant-current generators. The power expended in the series arc lamps could, therefore, be obtained with much less expense if it could be supplied from the constant-potential distribution system.

In order to meet the above requirement, a special type of transformer has been extensively introduced, called a constant-current transformer, which serves to transform alternating-current energy from constant pressure and variable current to constant current and variable pressure. Figs. 113 and 114 represent such a transformer, uncovered and covered respectively. In Fig. 113, $C' \ C \ C' \ C \ C'$ is a laminated iron frame, or core, of the transformer. The primary coil P, at the bottom of this frame

Fig. 113.—Interior of Air-Cooled Constant-Current Transformer.

is stationary and is electrically connected with the constant-potential generator, or mains, of, say, 2,000 volts pressure. The secondary coil *S*, is a movable coil and is supported by a pair of chains from a pivoted lever system counterpoised at *W*, in such a way that this coil is balanced and is free to move up and down the central core *C′*. This secondary coil is required to deliver a constant strength of alternating current at voltages that will vary with the load. When the secondary coil *S*, hangs low down, and close to the primary coil *P*, the apparatus will work at maximum load, with the constant secondary current and maximum secondary voltage. When, on the other hand, the coil *S*, hangs at the highest position and farthest from the primary coil, the voltage induced in the secondary circuit will be a minimum.

FIG. 114.—50-LIGHT AIR-COOLED CONSTANT-CURRENT TRANSFORMER WITH TAPS FOR OPERATION AT PARTIAL LOAD WITH FULL-LOAD POWER FACTOR.

When the apparatus is at work, the currents flowing in the primary and secondary coils repel each other, or exert a repulsive, lifting force upon the secondary coil *S*. This coil is so counterpoised that if the secondary current strength falls below the standard, the repulsion diminishes, and the coil *S* falls, thus approaching the primary winding and having its voltage increased, so as to enable it to send more current in the secondary circuit. If, on the other hand, the coil *S*, should send too strong a current into the secondary circuit, there will be an unduly powerful repulsive or lifting force exerted on the coil, which will rise away from the primary to a position in which the induced voltage will be lessened. As a result, for any given load, the coil *S*, will always hang at such a position as will maintain the required current strength in the secondary circuit.

Moreover, the strength of this current can be adjusted within certain limits by adjusting the counterpoise weight *W*. Adding to this weight will tend to diminish the strength of constant current, with the mechanism of Fig. 113.

The constant secondary alternating current required for the series arc lamps is usually either 6.6 amperes or 7.5 amperes. The former is intended to supply about 430 watts in each arc lamp, of which 400 appear in the arc, while the latter is intended to supply about 490 watts in each arc lamp, of which 450 appear in the arc. The pressure at the carbons is about 72 volts in either case.

These transformers are built in various sizes from 25 lights to 100 lights. Their efficiency at full load is about 95 per cent.

They require much less attention than a dynamo of the same size, and require much less space, power and cost than a dynamo of the same power. Their least satisfactory performance is in regard to idle magnetizing current, which is always considerable, and which makes their power-factor relatively low. At full load the power factor of a 50-light constant current transformer may be 77 per cent. That is to say, the power in watts delivered to the transformer will be about 77 per cent. of the apparent power or volt-amperes delivered. On light loads it is still less. By changing the connections of primary and secondary coils of Fig. 113 at times of light load, the power factor on light loads may be improved.

These transformers are constructed both for working in oil or for working in air without oil. The ventilation has to be

carefully provided for in the latter type, as shown in Fig. 113. The air-cooled transformer requires a dash pot *D*, to damp the oscillations of the movable system.

The connections of the transformer of Fig. 113 are indicated in Fig. 115. The primary terminals *A*, *B*, are led through fuses and plug switches to the ends *B*′ *A*′, which are connected to the constant-potential generator in the central station, or to the constant-potential distributing mains. The secondary terminals are led through wires *L M*, plug-switches s, s_2, to the series-arc circuit *a b c d*. s_3 is a short-circuiting switch for cutting off the load. Short-circuiting a constant-current circuit removes the load and is the equivalent of *opening* a constant-potential circuit.

By the use of a mercury-arc rectifier, it has recently become possible to operate

direct-current series arcs from an alternating-current constant-potential system, through transformers such as have been described above. That is to say, constant-

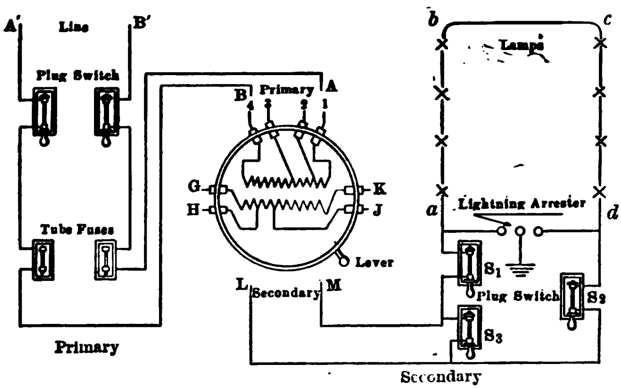


FIG. 115.—CONNECTIONS OF CONSTANT-CURRENT TRANSFORMER SUPPLYING SERIES ARC-LAMPS.

potential to constant-current transformers are now applied to direct-current series arc circuits through mercury-arc rectifiers.

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